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The Lost Generations of Engineers

By WILLIAM B. PLANK

Professor and Head, Dept. of Mining and Metallurgical Engineering, Lafayette College

While the energies and interests of the entire country have been centered on winning the war against Germany and Japan, two very important and significant educational considerations seem to have been overlooked by those who are planning for the successful culmination of the war in Europe and in the Pacific, and for the expected rapid development or reconversion of our industries after the fighting stops.

It is eminently right and proper that all elements of our society should make their respective contributions to the winning of the war, and I have no criticism whatever of any government agency which has had to put the common welfare and safety above the interests of any group.

It cannot be denied, however, that the successful prosecution of this war, more than of any other war in the history of the world, depends absolutely on the continued, phenomenal production of our American industries which, through the inventive genius and special skills of our American engineers, with the loyal support of labor, have produced and are producing the guns, ammunition, ships and armament that have made our Armed Forces invincible on all fronts.

In addition to the engineers in industry, the Armed Forces who are winning our battles against the enemy so magnificently, would be helpless without the peculiar, specialized, and brilliant abilities of the engineers in the uniforms of the Army, the Navy, the Marines, the Air Forces, and the Merchant Marine.

With these facts well-known and acknowledged by everyone, educators, whose job it is to train these engineers, are beginning to be alarmed at the present situation affecting the immediate and future supply of engineers to fill these absolutely vital functions in our nation's existence.

The two points in this situation that seem to have been overlooked are that, (1) Unless we begin immediately to make it possible for qualified young men to complete their formal engineering education, there may very well develop a critical shortage of engineers in the Armed Forces with a resultant prolonging of the war and, (2) Even though we begin at once to train engineers, the vacancy in the normal supply of engineers from our engineering colleges will never be filled, and the expected development of our industries after the war consequently may not be fully realized.

It is these "lost generations of engineers" about which I wish to speak, particularly. They are the men who, because of Selective Service, were prevented from completing or, in many cases, even beginning their formal education at the 150, or more, engineering colleges of our country. They are, for the most part, in the uniforms of our

Armed Forces. Although they may have received specialized training in the Army or Navy, their complete professional engineering education has been stopped, or at least seriously interrupted.

Ever since the Selective Service began to operate, especially after Pearl Harbor, the enrollment in the engineering colleges has been steadily dropping. In 1941–42, there were 115,000 engineering students in the engineering colleges of the United States and Canada, as compared with 42,000 today. This is a drop of 64 per cent in three years. These figures are from studies made by the Society for Promotion of Engineering Education.

What is more alarming, however, is that the number of students who may receive their engineering college degrees this spring will be only about one-fifth the number that graduated two years ago. In 1942–43, 14,714 men graduated in engineering in the U. S. and Canadian colleges, whereas there are only 3,000 senior engineering students in college today, and not all of them will likely receive degrees, for one reason or another. In normal years, between 12,000 to 15,000 engineering college graduates annually took their places in the industries of the U. S. and Canada.

The common belief that the returning veterans will flock back to the engineering colleges in large numbers appears not to be borne out by studies made by educational authorities. It is estimated that about 60,000 veterans might be expected to apply for technical and engineering training, but not all of these will likely want to take the time to complete professional engineering courses.

From the partial picture we now have of the educational desires of the veterans already returned to us, it is seen that, for the most part, they will want short, special, intensive training courses to fit them for a job as soon as possible. This kind of training will likely be given largely by the colleges in industrial communities where the veteran can work at a job during the day and go to school at night.

The type of institution best suited for this work is the so-called Technical Institute, where the objective is the training of technicians for industry, or the upgrading of them in occupations for which professional engineering school graduation is not required. This type of training is admirably fitted for immediate productivity on completion of the training program, and for the attainment of occupational goals sooner than is normally the case with graduates of engineering colleges.

From a recent study of vocational-technical training made by the U. S. Office of Education, it was estimated that, on the average, industry needs 5.2 technicians for each engineer. There are not enough technical institutes at present to train all the technicians that are estimated to be essential for industry in the post-war days.

The study shows that not less than 250 of such institutions will meet the needs of the Country, and that there should be one in each community of 50,000 or more.

It is the opinion of many educators, with whom I concur, that the professional engineering colleges should not attempt to provide the technical institute type of training because they do not have the proper facilities nor the staff to do the work well.

These colleges, in my opinion, should now be planning for the professional engineering training of the young men

now in secondary school. According to one estimate made last fall, three out of every four high school seniors expect to go to college and 43.4 per cent of these are planning to study engineering. The other choices in order are: medicine, law, business administration, agriculture, and physical education.

The effect on our national life of the absence of the "lost generations of engineers" can never be fully remedied.

Sections and Branches

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THE T-SQUARE PAGE

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DEVOTED TO THE INTERESTS
OF ENGINEERING DRAWING

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S.P.E.E. Summer School for Teachers of Engineering Drawing and Descriptive Geometry, June, 1946

Because of the governmental ban on conventions and the subsequent cancellation of the Annual Convention of S.P.E.E. which was to have been held at Washington University, St. Louis, Missouri, the arrangements for a summer school for teachers of Engineering Drawing and Descriptive Geometry to be held in conjunction with the convention have been dropped.

Upon the assumption that the ban will be lifted before June, 1946, and upon the further assumption that the Annual Convention will be held in St. Louis as originally planned, the Executive Committee of the Division of Engineering Drawing and Descriptive Geometry is actively preparing a program for a summer school to be held at that time.

The general theme has been divided into three sections as follows:

Pre-convention period—What training in graphics does industry require of college men.
Convention period—What training in graphics do college departments require of students.
Post-convention period—How shall graphics be taught in order to meet these requirements.

If the assumption made proves correct, Dean Alexander S. Langsdorf of the Schools of Engineering and Architecture at Washington University, St. Louis, will be the Director of the Summer School. Professor Randolph P. Hoelscher of the Department of General Engineering Drawing, University of Illinois, and first secretary of the Division of Engineering Drawing and Descriptive Geometry, will serve as Chairman of the Teaching Staff. Professor Roland W. Bockhorst of the Engineering Drawing Department at Washington University will serve as Secretary of the Summer School.

The members of the Summer School will be housed in dormitories at Washington University and meals will be provided at one of the dining halls except for the noon and evening meals during the S.P.E.E. convention period. The expense of attendance will be limited to a small registration fee and the cost of room and board.

Attendance will probably be limited but this detail will be worked out and presented later. Suggestions concerning the summer school should be sent to Professor Justus Rising, Purdue University, Lafayette, Indiana, Chairman of the Division of Engineering Drawing and Descriptive Geometry.

Post War Planning in Engineering Drawing

By RALPH S. PAFFENBARGER

Chairman, Department of Engineering Drawing, The Ohio State University

War Training Courses, under the Engineering Science and Management War Training Program, showed more demand for engineering drawing in a good many localities than for any other subject offered. Many specialized courses were offered in addition to the funda-

mental courses and a large number of trainees were able to extend their preparation until they held responsible jobs in design and construction in industry. Because of their lack of knowledge and inability to read and interpret drawings, many students took short courses in order to be able to become good operators. Many women took the training in order to become tracers and those showing much promise were able to advance quite rapidly in engineering offices. To meet their needs, due to manpower shortage, several large corporations organized short courses for women and trained them as engineering aides. Experience has shown that many of these programs have been very successful. Those having a scientific background as a basis of selection of trainees, will undoubtedly be continued after the war for training technicians and laboratory assistants. As shown by the new curricula being offered in all professional colleges, other than engineering, this type of training is going to be more and more in demand.

Many of the Army and Navy Programs, particularly with reference to engineering drawing, were laid out with rather indefinite objectives and frequently work had to be presented too rapidly, for thorough grounding in fundamentals, and hit and miss coverage of the subject matter resulted.

Curricula revision in a few colleges has resulted in some reduction in fundamental and professional subjects to allow the inclusion of broadening or humanistic courses without extending the period of study. As far as engineering drawing is concerned, where such changes have caused a reduction in time, it has weakened rather than strengthened the curricula. Unquestionably more emphasis is being placed upon the "graphic language" today than ever before. It is just as important now as it has been in the past that the engineer be thoroughly trained in his language and not be turned out professionally ignorant of a fundamental subject.

The objective for all engineers should be a thorough knowledge of the subject matter, rather than the development of drafting skills; both are important, but the real engineer will eventually be directing and supervising the work of others. It is essential that he have a knowledge of fundamentals, he must know how a drawing should be made, what information is needed, the correct form of notes and specifications, etc.

Basic engineering drawing courses in our post war planning should include more free hand drawing and sketching. This should be developed to the highest skill possible. The training in free hand drawing should begin in the first course and be carried along continuously. More work should be given in shape description, particularly pictorial drawing because of the added emphasis being placed on pictorial translation. More emphasis should be placed on size description and better standards and clearer methods developed for presenting the subject of dimensioning. Many applications should be given for a full coverage of decimal and limit dimensioning in detail and assembly working drawings. Visual aids offer a very important means of presenting fundamental material quickly and clearly, but unless this material is well selected and expertly produced, much time may be wasted in this effort.

Descriptive geometry courses should be developed so as to include practical applications and should come early in the curricula, so that opportunity for developing its use in advanced courses may be exercised.

Specialized courses worthy of consideration in a well rounded engineering drawing department should include such work as technical sketching, advanced machine drawing, production illustration, advanced descriptive geometry, aircraft drawing, engineering problems and graphical analysis, teacher training for high school teachers, lettering and illumination, and specialized objective courses.

Finally we should not overlook the fact that many of the returning veterans will welcome refresher or retraining courses in the material they covered many years back and we want to be able to offer all the opportunities possible for their assistance.

Accelerated Programs in Mechanical Engineering*

By DAVID L. ARM
Iowa State College

For the past several years, all of us have been participating in accelerated programs in mechanical engineering. Due to sensible policies of the selective service system, we have been able to operate these programs until rather recently with a sizeable group of students—a group large enough to provide an opportunity to compare results with the results secured under the normal nine-month plan.

In addition, many of us have participated in either ASTP or the Navy V-12 program and some of us, in addition, have been engaged in purely vocational training programs for the armed forces.

As a result of our participation in these programs, we shall attempt to summarize some of their advantages and disadvantages, to indicate some of the things which we might well consider carrying over, and to point out the features which we believe should not be adopted for our postwar programs.

One of the features of these service programs which has been especially good has been the number and types of visual aids which have been made available to the instructor. It is our belief that mechanical engineering instruction will be greatly benefited in the postwar period if we make greater use of movies and film strips, if we secure and use "blow-ups" or greatly enlarged pictures illustrating details of design, construction or operation, and if we have available more cut-away models and "mock-ups" of the more common mechanisms and machines which we study. In the past, too many of us have neglected to use material of this sort which has been made available to us.

It can be said that the curricula which have been prescribed for the service programs which we are teaching are uniformly good. The vocational training programs are accomplishing the results for which they were established—namely the training of men to install, maintain, repair, and operate various types of equipment. The Navy V-12 curriculum provides for a good basic training in mechanical engineering—good enough so that these men will be excellent engineering material for industry after the war. We have been in a particularly fortunate position to evaluate this curriculum, as at our institution we have just completed three 16-week terms exactly as specified by the Navy, and consequently have organized and taught all of the courses specified for mechanical engineering V-12 students.

The favorable characteristics of this curriculum are as follows:

1. It calls for an excellent thermodynamics and heat-power sequence.

* Presented at the 52nd annual meeting, S.P.E.E. (Mechanical), Cincinnati, June 22–25, 1944.

2. The mechanics sequence, with some slight modifications, is good.
3. The machine design sequence is fairly good—with some slight rearrangement in hours and the sequence of presentation of subject matter, it would be excellent.
4. The full-year course in electron tubes and circuits which is required is excellent.

The weak points are:

1. Too little metallurgy.
2. No shop practice.
3. Not enough management courses.
4. Too few courses in the arts or the social sciences, and no opportunity for electives in these fields.

We agree that the objections listed above are objections to this curriculum as compared to our peace-time program. We believe that the curriculum as specified is as good as could have been devised—keeping in mind the fact that the objectives are necessarily different from our usual objectives.

During the past year or so there have been indications that we will be urged to continue accelerated programs in engineering for some years after the war. In addition, there are some people who are beginning to advocate the adoption of the concentrated methods of the vocational programs in our professional courses. The second point, that of applying the vocational school techniques to our professional programs, should be strongly resisted. This type of agitation usually comes from people who still think of engineering as purely vocational.

We shall, however, be forced to consider seriously the suggestion that we continue accelerated programs for some years after the war. Pressure for this will come from two sources, in the main: From veterans who will be sent to college under government auspices, and from industry.

We have been able to discover only two advantages claimed for the accelerated program in peace-time. (We agree that the pressure of war demands has justified this acceleration over the past several years.) The advantages claimed are:

1. The student completes his undergraduate course in three years, thus making him available to industry one year sooner than under the normal program.
2. More economical use of college buildings and equipment when utilized twelve months of the year.

The disadvantages, as we see them, are as follows:

1. The accelerated program imposes too great a strain upon the faculty.
2. Continuous attendance and study lowers the efficiency of the student.
3. Neither student nor teacher has the opportunity for contact with industry by means of the summer job.

We believe that the disadvantages far outweigh the advantages of such a program, and in closing I should like to urge engineering faculty members to think seriously of what lies ahead. If we are forced to continue our accelerated programs, I believe that we should have a sufficient number of additional members of each of our staffs to enable every teacher to have one full term off each year so that he might write, study, do research, or work in industry. We should insist also that student attendance during the summer term be purely voluntary. In effect, what I propose is that we offer the *opportunity* for an

accelerated program for anyone who desires it, but that at the same time, we make provision to insure those procedures which will maintain maximum efficiency of the student and maximum effectiveness of the teacher.

I should like to urge also, that we adopt the good features of our present service programs for our postwar civilian teaching and that we strenuously resist being forced to adopt those methods and procedures which we do not consider to be applicable to a good professional education.

A.S.T.P. Experiences*

By W. W. COLVERT
Illinois Institute of Technology

The 366th Service Unit was established at Illinois Institute of Technology as a part of the Army Specialized Training Program. The instruction period began August 5th, 1943 and ended March 17th, 1944, with the general reduction of this program. During this period the first two and one-half terms of the work outlined under the Basic Engineering Curriculum was covered.

Soon after starting the instruction program, it became apparent that the work in physics as planned would take more than the allotted time for quite a large number of the men in the unit. Before class instruction was started, a mathematics preparation test, similar to that used with all of our freshman groups, was used to get some idea of the preparation of the members of the unit for the type of work planned. The test had been standardized with a mean score of 20 and a standard deviation of 4. Scores obtained are used in Tables 1 and 2. In addition, regular physics tests were given at approximately two week intervals. The mathematics department test scores and the AGCT scores were also available. An examination of the scores of these tests resulted in the transfer of some of the men to sections in which they would cover work equivalent to that of high school physics and mathematics courses. Other transfers, out of the unit, continued throughout the duration of the work. The disposition of the 500 men originally in the unit is indicated by the following tabulation:

Transferred out before the end of the term	41
Transferred to review sections	72
Recommended to repeat the work of first term (Due to illness)	5
Reported as having failed	83
Recommended for second term	299

Replacements were added to the unit to build its strength to 486 men at the beginning of the second term. The disposition of these men is shown by the next tabulation. Replacements and men originally in the unit are listed separately, in order to keep track of the members of the original group.

Replacements:	
Transferred during term	6
Reported as unsatisfactory	11
Recommended for following term	170
Of original group:	
Transferred during term	22
Recommended to repeat work (Due to illness)	8
Reported as unsatisfactory	43
Recommended for following term	226

Only 45 per cent of the men of the original group of 500 remained, after two terms, in this unit among those recommended as qualified to continue as members of the A.S.T. group.

In an effort to determine a cause for the losses from the group, due to failure academically, an examination of the data obtained from two tests was made. The mathematics preparation

* Presented at the 52nd annual meeting, S.P.E.E. (Physics), Cincinnati, June 22–25, 1944.

TABLE 1

CLASSIFICATION BASED ON INTELLIGENCE TEST AND MATHEMATICS PREPARATION TEST

	A 14–16	B 17–19	C 20–22	D 23–25	E (Includes 3, 29–30)	
					26–28	Total
a 115–119	33 8	3r 82 38	1r 28 25	12 12	4 4	4r 159 87
b 120–124	11r 26 3	13r 72 38	32 30	7 6	3 3	24r 140 80
c 125–129	13r 19	13r 36 17	3r 27 23	15 14	3 3	29r 100 57
d 130–134	3r 3	4r 27 18	5 4	3 3	6 5	7r 44 30
e 135–160	1r 3 1	4r 15 8	2r 17 15	6 6	1r 9 8	8r 50 38
Total	28r 84 12	37r 232 119	6r 109 97	43 41	1r 25 23	72r 493 292

test, previously mentioned, was scored for 493 men and scores which depended primarily upon intelligence quotient were obtained for most of the men. The classification based upon these two tests is shown in Table 1.

The numbers at the top of the columns 14–16, 17–19, etc., represent the scores on the mathematics preparation test and the numbers in the left hand column are proportional to intelligence quotient. This intelligence test had a mean score of 100 and a standard deviation of 20.

This table gives the distribution at the beginning of the first term and also indicates in part the disposition of the men who left the unit. The center number shows the initial size of a particular group, the numbers in the upper left corners marked such as 3r indicate men assigned to review sections and the numbers in the lower right positions shows the composition of the unit at the end of the first term.

Of the thirty-three men in the 'A,a' group, only eight started the second term. Thirty-eight men of the 'B,a' group started the second term, three men were sent to a review section and forty-one were shipped out. If we examine the four groups, A,a A,b B,a and B,b, we find a loss of one hundred and twenty-six men. Twenty-seven of these were sent to review sections; the other ninety-nine were shipped out. Since only thirty additional men were shipped out from the unit, the loss from these four groups was more than three times the loss from the remaining

groups. The percentage loss from these four groups was 53 per cent as compared with a percentage loss of 13 per cent for the remaining groups. According to these data, a man who made a low score on both of these tests had about one-fourth the chance of doing satisfactory work that a man had whose scores did not fall in one of these four groups. The percentage loss for the entire unit, omitting those sent to review sections, was 30 per cent of the 421 remaining.

In an effort to determine the relative effect of low intelligence quotient as compared with poor preparation in mathematics, the losses of all the row 'a,' intelligence test score 115–119, groups was compared with the losses of all the column 'A,' mathematics preparation test score 14–16, groups. Omitting those sent to review sections, the losses were 44 per cent for the row 'a' groups as compared with 77.5 per cent for the column 'A' groups. In like fashion, the losses of the row 'b' groups amounted to 31 per cent while the losses of the column 'B' groups amounted to 39 per cent. It would seem then that these results are in agreement with the statement of Lt. Col. Palmer's paper, published in the S.P.E.E. JOURNAL in December 1943, that "The greatest single difficulty has been the over emphasis, by some, of the candidate's intelligence quotient and the under emphasis of his educational background."

Table 2 shows the distribution of the remaining men of the original unit

TABLE 2

CLASSIFICATION BASED ON INTELLIGENCE TEST AND MATHEMATICS PREPARATION TEST

	A 14–16	B 17–19	C 20–22	D 23–25	E (3 men, 29–30)	
					26–28	Total
a 115–119	33 8 4	79 38 22	27 25 18	12 12 11	4 4 3	155 87 58
b 120–124	15 3 1	59 38 23	32 30 22	7 6 6	3 3 3	116 80 55
c 125–129	6	23 17 15	24 23 15	15 14 13	3 3 3	71 57 46
d 130–134	6	23 18 18	5 4 3	3 3 3	6 5 5	37 30 29
e 135–160	2 1 1	11 8 8	15 15 13	6 6 6	8 8 6	42 38 34
Total	56 12 6	195 119 86	103 97 71	43 41 39	24 23 20	421 292 222

at the end of the first month of the first term and at the beginning of each of the other terms. The mathematics preparation and intelligence test scores are used as in Table 1.

The top number shows the number in the group at the end of the first month after omission of the men sent to review sections, the middle number shows the number in the group at the beginning of the second term and the lowest number shows the number remaining at the beginning of the third term. The replacements are not included in this tabulation.

Of the eighty-seven men in the four groups, 'A,a A,b' 'B,a' and 'B,b,' who started the second term, thirty-seven men were shipped out before the beginning of the third term showing a loss from these groups of 42.5 per cent. Only forty-three of the remaining two hundred and five men were eliminated with a loss from these groups of 21 per cent.

The record for the replacements sent in for the second term was quite different. Six men were transferred out for some reason and eleven men failed to do satisfactory work throughout the term. The total loss from this group amounted to approximately 9 per cent for the term.

In any effort to evaluate such a program, we should first agree upon the objective or objectives. If the purpose was primarily to choose and train only a fractional part of the initial group selected, the system might be judged as satisfactory. And, the idea that such was a purpose was mentioned more than once. If, however, the purpose was to give to the greatest number possible such training as might be of use to the Army, the conclusion could be quite different.

It has been suggested that the results of this program be studied in relation to the general problem of the location of physics courses in engineering curricula. This program offers a rather unusual opportunity to see what our high school system is producing since financial ability had nothing to do with the composition of the group.

There were many excellent students among the members of this unit; students of whom any institution could be proud. In spite of this fact, as well as the fact that many of us enjoyed working with these men, we would have preferred that many of them either have a better preparation in mathematics or that they be given a different type of course.

If only a single year of physics is included in an engineering curriculum it seems that more could be accomplished by waiting until the preparation for physics has been improved beyond that too often found among entering students. Many of the students lost from A.S.T. units might have surmounted the academic difficulties in physics had been given later in the course. The purposes for which the program was developed might not have been served as well, however, with such a change in the curriculum.

It would seem then as if the problem of the proper location of the physics courses in an engineering curriculum is only a part of the greater problem of "how much time can properly be devoted to the study of physics." And, the question "how much mathematics has the student learned" must be considered in any satisfactory solution of either the problem of proper location or the problem of proper content of physics courses. These conclusions would, it seems, be supported by the data recorded for this A.S.T. unit, at least.

Slide Rule Applications to Algebraic Equations*

Solution of the Cubic Equation

By ANDREW R. WEBER

Professor of Mechanical Engineering,
University of Dayton

The principle underlying the solution of the cubic equation by means of the slide rule is analogous to that of the quadratic. The cubic equation is first put into such form as to permit the application of the slide rule to its solution. Again it is mentioned that only the real roots can be obtained by this presentation. The relative values of the linear scales C and D and of the square scales A and B are the bases of solution of the cubic by means of the slide rule.

The Cubic of the Form: $x^3+px+q=0$

Algebraic Theory Involved.

The general form of the cubic in the p-form is:

$$x^3+p_1x^2+p_2x+p_3=0. \tag{1}$$

from which the reduced form:

$$z^3+pz+q=0 \tag{2}$$

can be obtained in several ways, such as:

1, increasing each root by $\frac{p_1}{n}$, where $n=3$;

2, by the functional relationship $f(x)=0$; and $f(z+h)=0$;

3, by synthetic division, letting $x=z-\frac{p_1}{n}$.

In the reduced equation notice that:

1, the coefficient of the squared term disappears from the cubic;

2, x becomes known as soon as z is known, for $x=z-\frac{p_1}{n}$;

3, the cubic has three roots, one or three being real.

Let x_1 designate the single real root, or the numerically largest of the three real roots as the case might be, and x_2 and x_3 the remaining roots. Then, $(z-x_1)$, $(z-x_2)$, and $(z-x_3)$ are the factors of equation (2). Multiplying these factors together, we get:

$$z^3-(x_1+x_2+x_3)z^2+(x_1x_2+x_2x_3+x_3x_1)z-(x_1x_2x_3)=0. \tag{3}$$

*Weber, A. R., "Slide Rule Applications to Algebraic Equations," The Journal of Engineering Education, June, 1943.

Comparing coefficients of equations (2) and (3), we see that:

$$x_1+x_2+x_3 = 0, \tag{4}$$

$$x_1x_2+x_2x_3+x_3x_1 = p, \tag{5}$$

$$x_1x_2x_3 = -q. \tag{6}$$

Letting $x_2x_3=m$, we have from equation (5):

$$x_1x_2+x_2x_3+x_3x_1=p,$$

$$x_1x_2+ m +x_3x_1=p,$$

or

$$m+x_1(x_2+x_3) =p,$$

but

$$x_1=-(x_2+x_3) \text{ from equation (4)},$$

hence,

$$m+x_1(-x_1)=p,$$

or

$$m-x_1^2=p \tag{7}$$

and, from equation (6),

$$x_1m=-q. \tag{8}$$

From equations (7) and (8) we notice that:

1, m is essentially a positive quantity; for,
if x_2 and x_3 are real, they have like signs, therefore, their product is positive; and,
if x_2 and x_3 are complex, again their product is positive.
2, the sign of x_1 is opposite that of q.
3, x_1^2 is greater or less than m according as p is negative or positive.

The discriminant of the reduced cubic equation is given by:

$$D=\left(\frac{q}{2}\right)^2+\left(\frac{p}{3}\right)^3 \tag{9}$$

and, as it may be positive, negative, or zero, it determines the nature of the roots. When, therefore,

1. $D<0$, one root is real, and two are complex;
2. $D=0$, all roots are real, and two are equal;
3. $D>0$, all roots are real, and unequal.

Further, from our knowledge of the cubic equation, the signs of the roots may be readily determined. Previously, it was assumed that x_1 is the numerically largest root and its sign is opposite to that of q of the reduced cubic. The signs of x_2 and x_3, the remaining roots, are similar since the roots are real. Now the product of x_1x_2 is essentially negative, *i.e.*,

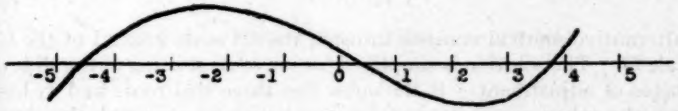
$$x_1x_2=-n, \tag{10}$$

hence, as soon as the sign of x_1 is known, those of x_2 and x_3 are at once determined.

By applying the location principle, we can ascertain the approximate value of x_1; *i.e.*, we can find the consecutive integers between which x_1 lies. Thus,

$$x^3-17x+12$$

is negative when $x=-5$, and positive when $x=-4$. Consequently, the expression changes sign by passing through 0; or, in other words it has a root between -5 and -4. This root is the numerically greatest root, for, since the sum of the roots is equal to 0, according to equation (4), there can be no other negative roots and the remaining roots must be numerically smaller than x_1.



Slide Rule Setting

To solve the equation

$$x^3-7x+7=0$$

by means of the slide rule, we adjust the slide by trial until the reading on scale A over the index of scale C and the reading on scale C or q on scale D differ by p. At the index of scale C we read the root on scale D.

This procedure can be detailed as follows:

1. Write the equation in the form of $x(x^2-7)=-7$.
2. If the slide is in such position that its index is over the correct value of x on scale D; then, over 7 on scale D must be the other factor, (x^2-7), on scale C.
3. The reading on scale A above x on scale D is x.
4. Hence, the solution of the equation is accomplished by setting the slide so that 2.3 on scale C over 7 on scale D and 9.3 on scale A summate to 7, the coefficient of the x-term. The root, 3.05, is read on scale D at the index of scale C. The sign of the root is minus $(-)$.

A	9.3		
	C 1	2.	3
D	3.05	7	

The other two roots are found by repeating step 4, above. Thus:

2.9 on scale A above the index of scale C, and 4.1 on scale C below the hairline of the indicator which is in alignment with 7 on scale D summate to 7, the coefficient of x, and 1.7 on scale D at the index of scale C is a root. The sign of the root is plus $(+)$.

A	2.9		
	C 1	4.	1
D	1.7	7	

1.8 on scale A above the index of scale C, and 5.2 on scale C below the hairline of the indicator which is in alignment with 7 on scale D summate to 7, the coefficient of x, and 1.345 on scale D at the index of scale C is a root. The sign of the root is plus (+).

A		1.8		
	C	1	5.	2
D		1.34	7	

An alternative method consists in using the CI scale instead of the C scale with scale D. The solution is simplified for it avoids shifting of the slide during the process of adjustment. If the cubic has three real roots and x_1 has been obtained, the other two roots may be found without changing the setting by noticing that x_1x_2 is essentially negative, and thus we have from equation (5):

$$\begin{aligned} x_1x_2+x_2x_3+x_3x_1 &= p \\ -n+x_3(x_1+x_2) &= p, \quad \text{letting} \quad x_1x_2=-n \\ -n+x_3(-x_3) &= p, \quad \text{since} \quad x_3=-(x_1+x_2) \\ -n-x_3^2 &= p \\ n+x_3^2 &= -p. \end{aligned} \tag{11}$$

Hence, if we find the sum of the readings on scale A and on the CI scale that amounts to p, we read by means of the indicator the remaining two roots, x_2 and x_3, at the corresponding points on scale D.

Applying this method to the equation

$$x^3-7x+7=0,$$

we observe the following procedure:

Set the index of scale CI to 7, (q), on Scale D.

Find a number on scale A and a number on scale CI which summate to 7, (p), the coefficient of the x-term. This combination of numbers is 9.3 on scale A and 2.3 on scale CI.

On scale D in alignment with 9.3 and 2.3, read 3.04 which is a root.

Without change of setting of the slide, move the indicator until another combination of numbers on scales A and CI summate to 7, (p). This combination is 2.9 on scale A and 4.1 on the CI scale.

On scale D in alignment with 2.9 and 4.1, read 1.7 which is a root.

Again, shift the indicator without change of slide setting for the third combination of numbers on scales A and CI that summate to 7, (p). This combination is 1.8 on scale A and 5.2 on the CI scale.

On scale D in alignment with 1.8 and 5.2, read 1.346 which is a root.

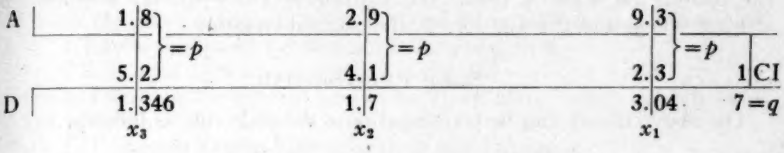
It is evident that:

3.04 is x_1, and its sign is negative since q is positive.

1.7 is x_2, and its sign is positive since $x_1x_2=-n$, and x_1 is negative, therefore x_2 is positive.

1.346 is x_3, and its sign is positive since x_2 and x_3 have like signs when they represent real roots.

Therefore, -3.04, 1.7, and 1.346 are the roots desired.



Illustrations of Slide Rule solutions

1. $x^3+2x-5=0$.

Procedure:

Set the index of scale CI to 5 on scale D; shift the indicator so that 1.77 on scale A and 3.77 on scale CI are in alignment; read 1.33, which is a root, on scale D in alignment with 1.77 and 3.77 on scales A and CI, respectively.

Since q is negative, the sign of the root is positive.

The other two roots are complex and can be determined as follows:

Applying the discriminant to the reduced equation, we get

$$D=\left(\frac{q}{2}\right)^2+\left(\frac{p}{3}\right)^3=\frac{25}{4}+\frac{8}{27}>0,$$

hence, one root of $x^3+2x-5=0$ is real, and the remaining two roots are complex.

2. $x^3-19x-30=0$.

Procedure:

Set the index of scale CI to 3 on scale D; shift the indicator so that 25 on scale A and 6 on scale CI are in alignment; read 5, which is a root, on scale D in alignment with 25 and 6 on scales A and CI, respectively.

Since q is negative, the sign of the root is positive.

Without change in setting of the slide, shift the indicator so that 9 on scale A and 10 on scale CI are in alignment; read 3, which is a root, on scale scale D in alignment with 9 and 10 on scales A and CI, respectively.

Since $x_1x_2=-n$, and x_1 is positive, x_2 must be negative.

Without change in setting of the slide, shift the indicator so that 4 on scale A and 15 on scale CI are in alignment; read 2, which is a root, on scale D in alignment with 4 and 15 on scales A and CI, respectively.

Since x_2 and x_3 have like signs, x_3 is negative.

Therefore, 5, -3, and -2 are the roots desired.

The Cubic of the Form: $x^3+p_1x^2+q=0$

Algebraic Theory Involved.

$x^3+p_1x^2+q=0$ may be written as $x^2(x+p_1)=-q$. When the index of scale C is set to x on scale D, x^2 is read on scale A. Now the logarithmic length of

scale B from the index to the hairline of the indicator represents $(x+p_1)$; hence the reading on scale A below the hairline is $x^2(x+p_1)$, or, $x^3+p_1x^2$. But $x^3+p_1x^2=-q$; and $x^3+p_1x^2+q=0$, the original equation.

Slide Rule Setting

The above theory can be translated onto the slide rule as follows:

Set the indicator to q on scale A.
Shift the slide so that the number on scale D below the index of scale C and the number on scale B below the hairline summate to $(x+p_1)$, the coefficient of x^2.
The desired root is the number on scale D below the index of scale C.
The sign of the root is determined as previously discussed.

This procedure is illustrated in the examples that follow.

1. $x^3+x^2-12=0$.

Procedure:

Set the indicator to 12 on scale A.
Shift the slide so that 2 on scale D below the index of scale C, and 3 under the hairline of the indicator on scale B summate to 1, the coefficient of x^2.
The root is 2; and since q is negative the root is positive.
The remaining two roots are complex and can be determined as follows:
Since 2 is a root of $x^3+x^2-12=0$, then $(x-2)$ is a factor of the cubic, *i.e.*,

$$x^3+x^2-12=(x-2)(x^2+3x+6)=0.$$

Applying the discriminant of the quadratic to

$$x^2+3x+6=0,$$

we get

$$D=p^2-4q=9-24=-16.$$

Therefore, the roots of the quadratic are complex.
Hence, $x^3+x^2-12=0$ has but one real root and two complex roots.

A		1	2
	B 1		3
D	2		

2. $x^3+4x^2-4=0$.

Procedure:

Follow the general procedure given above.
0.904 on scale D, and 4.9 on scale B summate to 4, nearly.
0.904 on scale D is a root; its sign is plus (+).

The remaining two roots are real as determined by the discriminant for the reduced quadratic.

Follow the general procedure given above using the left index of scale C:

1.2 on scale D and 2.8 on scale B summate to 4.

1.2 on scale D is a root; its sign is minus (−).

Again, following the general procedure given above using the left index of scale C:

3.71 on scale D and 0.29 on scale B summate to 4.

3.71 on scale D is a root; its sign is minus (−).

Therefore, 0.904, −1.2, and −3.71 are the desired roots.

The Cubic of the Form: $x^3+p_1x^2+p_2x+q=0$

Algebraic Theory Involved.

The general form of the cubic is changed to the reduced form by the relation

$$x=z-\frac{p_1}{n}. \tag{12}$$

The reduced form in terms of z is then solved as previously treated. Having obtained the value of z, the root of the original results by substituting properly in equation (12).

By way of remark it is to be noted which root is represented by x_1 in the reduced form. Depending upon the relation as expressed by equation (12), it does happen that the largest numerical root of the transformed equation results in the smallest numerical root of the original; and vice versa.

Slide Rule Setting

1. $x^3+6x^2+3x+18=0$.

$x=z-2$; therefore, $z^3-9z+28=0$.

Procedure:

Set the index of scale CI to 28 on scale D.

Shift the indicator till 16 on scale A, and 7 on scale CI summate to 9, the coefficient of z.

The root, 4, is read on scale D below the hairline setting.

Since q is positive, the root is negative, *i.e.*, $z_1=-4$.

Since $x=z-2$, the root of the original equation is −6.

The remaining two roots are complex since

$$D=\left(\frac{28}{2}\right)^2+\left(\frac{-9}{3}\right)^3>0$$

for the reduced equation.

2. $x^3+15x^2-33x-847=0$.

$x=z-5$; therefore, $z^3-108z-432=0$.

Procedure:

Similar to Example 1.
144 on scale A and 36 on scale CI summate to 108. 12 on scale D is a root; its sign is plus (+); *i.e.*, $z_1=12$.
Since $x_1=z_1-5$, the root of the original equation is 7.
36 on scale A and 72 on scale CI summate to 108. 6 on scale D is a root; its sign is minus (−); *i.e.*, $z_2=-6$.
Since $x_2=z_2-5$, the root of the original equation is −11.
The reduced cubic has a double root; *i.e.*, $z_2=z_3$, since

$$D=\left(\frac{432}{2}\right)^2+\left(\frac{-108}{3}\right)^3=46500-46500=0.$$

Since z_2 and z_3 have like signs, $z_3=-6$.
Therefore, the remaining root of the original equation is −11.

Therefore, 7, −11, −11 are the roots desired.

The Cubic of the Form: $x^3+p_1x^2+p_2x=0$

Algebraic Theory Involved.

Upon factoring the given form, we get

$$x(x^2+p_1x+p_2)=0.$$

Either one, or both of the factors may be equal to 0.
If $x_1=0$, we have a root of the original equation, *i.e.*, $x_1=0$.
If $(x^2+p_1x+p_2)=0$, we have the case of the affected quadratic which has been previously treated.

The Cubic of the Form: $x^3\pm q=0$

Algebraic Theory Involved.

Factoring $x^3\pm q^3$ we get $(x\pm q)(x^2\mp qx+q^2)$. Equating the first factor to 0, the first root of the original equation is obtained as $x=\mp q$. Equating the second factor to 0, and applying the discriminant to the affected quadratic we find that the second and third roots are complex.

Putting the equation into the form of $x^3=\mp q$, the solution thereof is accomplished either on the K scale in conjunction with scale D, or by means of the LL scales in conjunction with scale C. The latter method is to be preferred because of the absolute values of the numbers imprinted on the LL scales which eliminates the need of evaluating the answer as read on scale D.

Post-War Chemical Engineering Education from the Standpoint of the User of Chemical Engineering Talent*

By R. B. WITTENBERG

International Minerals & Chemical Corp.

Twenty years ago, almost to the day, I was handed that rectangular piece of sheepskin, engrossed in classical Latin, which announced to the world in general that I had become a chemical engineer. It took four long years, at what I then considered hard labor, to earn the title of chemical engineer—and another four years of post-graduate work in the University of Experience to prove that I wasn't one!

During the last twenty years, it has been my privilege to work in the chemical industry, closely associated with chemical engineers, and to observe them in research, production, sales, and executive functions. I am, therefore, laying before you my observations on the chemical engineer based entirely on the industrial and objective viewpoint—with which perhaps you may not be in complete agreement.

In one sense this meeting may be considered one between manufacturer and consumer. You as the manufacturer are facing new market requirements, and I as a representative of the consumer am suggesting certain possible revisions in the specifications of your product to make it even more valuable and useful in the post war years.

Training the chemical engineer today is a most difficult and arduous task. He is by necessity a hybrid product, for in the four to six years available for training, he must secure a sound knowledge of chemistry, physics, civil engineering, structural engineering, electrical engineering, mechanical engineering, and in addition must become a first class pipe fitter. Almost all of these subjects alone are full college courses. I feel that our technical schools are to be congratulated on the amazing job they do in the limited time available.

The chemical engineering course of necessity is crowded, and little or no time is left for non-technical subjects or for extra-curricular activities. This is a most serious handicap to the student. It is indeed the rare student who can find time for athletics or other non-classroom activities. It is particularly unfortunate that during these formative years the chemical engineering student must pass up many of the activities which would help to make him a well rounded personality.

Because of his necessarily intense training, the chemical engineering student has a tendency to become a lop-

*Presented at the 52nd annual meeting, S.P.E.E. (Chemical), Cincinnati, June 22-25, 1944.

sided character. It is as though he spent four years learning to ride a bicycle with only the right pedal. His right leg muscles become abnormally developed; the left muscles almost atrophy. When he dismounts from the bicycle on graduating, he can only limp through life—at least until the left leg by use and experience regains some usefulness; and I am sorry to say that too many chemical engineers never lose that limp. We have spent so much time and effort giving the student the tools by which he can make a living that we have left out the few tools which will help him make a life.

It may seem unorthodox to you that a chemical engineer should suggest "liberalizing" the chemical engineering course, but I am doing so for very practical and hard-headed business reasons. By giving the chemical engineer those few extra tools, he becomes more valuable to industry, and far more valuable to himself.

A few weeks ago I was talking with an old friend who has been remarkably successful in several different fields of endeavor. We were discussing the causes of success or failure of men in industry, and he stated it this way: "Every man has new and valuable ideas, but only a few *do anything about them.*"

A good idea, a new invention, remains just that *unless something is done about it!* The chemical industry today depends upon its chemical engineers for new ideas, *but it is up to the chemical engineer to do something about them.* That "doing something" consists of interesting *other people* in the idea—or in plain English, *selling the idea to others.*

The chemical engineer, if he is in research, must gain the enthusiastic support of his Research Director by means of the report he writes. If the engineer is seeking to establish his own enterprise, he must interest venture capital in his project. In either case he must transmit his idea clearly, forcefully, and in such a way as to inspire action by others. There is just one tool to do this job—the English language, written and spoken!

Please do not misunderstand me. I am not—definitely not—interested in making salesmen out of chemical engineers, but I want to stress the fact that in our modern complex industry, the chemical engineer must deal with other people: he must transmit his ideas to other people, and the English language is the one tool available to do this job.

All too many chemical engineers today simply do not know the English language and its use. You know many engineers, and so do I, who bounce from job to job at frequent intervals but get nowhere. They are "misunderstood," become discouraged, and quit or are discharged—mainly because they cannot put their ideas into writing or use the spoken word clearly and forcefully.

Please, gentlemen, please teach chemical engineers how to use the English language! To speak it and to write it!

And now a word about reports. In writing reports the average engineer presents all the facts and all the unknown factors in usually hodge-podge order without discrimination. Because there are always so many unknown and variable factors, the engineer is likely to be indefinite in his conclusions and to qualify them to such an extent that the report may be valueless. In his effort to be completely accurate and present all data, he usually succeeds only in creating confusion in his report; and the conclusions are nearly always tucked away at the back end

of the report where they can be found only with difficulty!

The average chemical engineer somewhere developed the peculiar idea that reports are to be written. Actually they are to be read. If the report is to produce action, the chemical engineer must consider the report from the reader's viewpoint.

Not long ago I requested a chemical engineer to visit a plant, confer with the plant manager, and make recommendations for instrumentation in the plant. The engineer and the manager did not reach a complete agreement, and upon rendering his report the engineer prepared a voluminous document proving that the plant manager's proposal was unsuitable—but he failed to state concretely what instruments should be installed. He became so interested in winning an unimportant controversy that he overlooked the job he was sent to do—namely, to tell the management what instruments were needed, where, why, and how much expense was involved. His report, instead of being helpful, actually created confusion: first, because he failed to think objectively of the job he was sent to do, and secondly because his report was written in such a manner as to becloud the issue.

An executive of a large company recently told me: "So-and-so is a fine chemical engineer, but he will never give me an unqualified answer to any question." In other words this engineer could not discriminate between essential and inconsequential data and present his knowledge in a way that was usable to his employer.

It is not enough, gentlemen, to give chemical engineers sound technical training; for somewhere in his college training, he must learn to transmit his ideas to other pepole, to deal with people, and to get along with people.

It makes no difference whether the chemical engineer is engaged in research, production, sales, or administration: he must work with other people harmoniously and productively, and this can best be learned in college. This can be accomplished without adding a single course to the present crowded schedule, by provoking classroom discussion—getting the students to "think on their feet," by providing for team work in the laboratory and by giving credit for well prepared reports as well as for subject matter.

The chemical industry today is complex and becoming more so daily. Because it is so highly integrated, mere knowledge of the chemical engineering "unit processes" is not enough. The chemical engineer should have at least some training in the basic principles of the business, some knowledge of what makes it "tick." Few chemical engineers in research or production work today have any knowledge of the economics of the industry.

The chemical industries are not in business today to make chemicals. Stripped of all "glamour" and romance, the chemical industries are operated for just one reason—to produce profit dollars, dividend dollars for stockholders. Too frequently the chemical engineer overlooks this; hence, somewhere in his college course he should be given a good dose of basic economics —not only the basic laws of supply and demand, the law of diminishing returns, the meaning of place utility, but he should see these laws applied to specific chemical problems.

Many a chemical engineer has wasted years of his life trying to develop desert deposits that are commercially worthless because they lacked "place

utility"—because God didn't locate the deposits on a railroad or near a market.

It was my unpleasant duty a few years ago to study and report on a semi-desert enterprise which attempted to recover values from a dilute brine using "free" heat. Literally several million dollars had been spent on the process, and losses were accumulating. On analysis the project was located too far from market, the brines were far too dilute, and the so-called "free" heat was actually extremely costly. It was hopeless and had to be closed and abandoned. All the time and money spent on the project could have been saved if the inventor had first determined the basic economic factors.

Few chemical engineers know how to make the financial and cost estimates so necessary to industrial management. Those who do know, usually learned the hard way—from bitter experience, and unfortunately frequently with the loss of other people's money.

Any chemical engineer in industry, whether engaged in research or production, must make cost estimates. The research worker may be studying several alternate processes, the choice of which depends upon plant and production cost factors. The production man must determine his optimum operating rates, and optimum chemical conditions may not always produce the lowest overall production costs.

In estimating the cost of a new plant, I have seen chemical engineers determine accurately the cost of equipment and forget to add the cost of a building to house the equipment. I once saw a huge plant that was actually built without a process sewer—later added at excessive cost. To offset this sort of thing, somewhere in his training the chemical engineer should get an "overall" view of the requirements of a chemical plant—water supply, process sewer, sanitary sewer, fuel supply, power supply, labor, etc.

Perhaps we have laid so much stress on "unit processes" of chemical engineering that the student did not see the whole picture in proper perspective; and without this perspective, he is not competent to make accurate plant cost estimates.

The average chemical engineer, until he has taken a post-graduate course in the hard school of bitter experience, simply cannot make accurate cost estimates. He can and does calculate raw material, fuel, and power costs very well and then gets lost. He will calculate labor costs on the basis of three shifts per day, forgetting that there must be a swing shift or that time-and-one-half must be paid for over 40 hours per week. He always forgets to add unemployment insurance and old age benefit taxes as costs, which are directly related to payroll and may add as much as 5 per cent. He invariably forgets to allow for vacation pay (another 4 per cent) and nearly always figures labor rates too low. He usually forgets that a plant must be maintained and either leaves maintenance supplies and labor out of his estimate or provides inadequately for them. Depreciation is a most bewildering item, frequently confused with maintenance or interest on the investment or both. It is either forgotten entirely or estimated on an arbitrary basis without regard for the process factors—corrosion for example—which affect it. Frequently package cost is neglected or if it is included, the cost of packing labor is always left out. I have never yet seen a chemical engineer make provision in a cost estimate for storing and shipping the finished product.

According to many chemical engi-

neers, plants are supposed to operate without such luxuries as a plant manager, office clerk, paymaster, shipper, watchman, or maintenance engineer. At least they seldom, if ever, provide for these costs in their estimates.

The mysteries of fixed and variable costs are inscrutable to most young chemical engineers. They simply do not grasp that there are certain costs which continue whether the plant operates or not, and that there are other costs directly proportional to production.

Until he has learned the hard way from experience, the chemical engineer always assumes that his plant will operate at full capacity—365 days per year; and he calculates his costs accordingly. He forgets that mechanical failure and human error, as well as necessary clean-up periods, will normally produce a 5 to 10 per cent drop in the load factor. He also forgets that seasonal market conditions may curtail operations, so he blithely makes his estimates on the full capacity basis and forgets to determine operating costs at several points on the cost curve.

After the production cost estimate has been made, the young engineer finds that according to his figures he can make his product, let us say for 10¢ per pound. He picks up a trade journal and finds the product quoted at, let us say 30¢ per pound. He calculates the difference of 20¢ per pound and calls it pure profit and may make the sad mistake of convincing some unenlightened backer to finance the venture on this basis.

He does not realize that prices quoted in trade journals are almost always for small spot lots and that actually the product may sell 10 per cent to 30 per cent below the published figures. He always forgets the mere detail of selling costs and general administrative costs which may be as low as 3 per cent or as high as 48 per cent of the selling price. He may overlook the fact that freight must be paid to get the product to market, and frequently must be equalized with a competitor whose plant is nearer the consumer. And there is, of course, the little matter of profits taxes if the project should accidentally make a profit after all these misadventures in estimating. Instead of having a 20¢ per pound profit as he calculated, the venture may actually produce serious losses.

Gentlemen, I am not discussing mythical cases, or to use an expression current in Washington "seeing spooks under the bed." I have seen chemical engineers make these very mistakes, and I must confess I have made them myself. Is it any wonder that the financial and administrative officers in the industry look slightly askance at the chemical engineer and frequently doubt him?

You may say, quite properly, that cost and financial estimating are outside the sphere of chemical engineering. Perhaps so, but on new projects, particularly in research and development, the chemical engineer *must* make the first estimates; first, to prove to himself that he is working on the right method, and second, to secure the interest and backing of his superiors in advancing the project.

Recently a young chemical engineer of my acquaintance worked out a new and technically interesting process to make a certain product. He aroused considerable interest on the part of the executives of his company until someone else went to the trouble of making a cost estimate on the process and

found that the product made this way would only cost three times the normal market price. The engineer was badly disappointed, and the incident made the company executives feel that he was just another "screwball chemical engineer." He would have saved himself many days of useless work and would have preserved his good reputation if in the beginning he had made his own cost estimate and abandoned the project.

Please understand, I am not advocating that the chemical engineer be made into an accountant—far from it; but I do urge he be given in a course of chemical economics the basic principles that he will need to make reasonably accurate estimates, and that he be given some idea of the financial background of the industry. In this work on chemical economics, the student should get some concept of chemical markets and their nature; and I can assure you these markets may be complex.

In his college training, the chemical engineer is well grounded in research and production unit processes; but the final "unit process" of the industry is neglected. The final "unit process" I refer to is the exchange of the finished product for the consumer's dollar.

Often I have heard research and production men say: "If we can make our product cheaper, we can sell it cheaper and increase our volume and our profits." Basically that is sound logic, but unfortunately many products have inelastic markets where even drastic price reductions will not increase consumption by a single pound.

I have heard production men say: "Well the trade wants monoclinic crystals, but we can make rhombohedral crystals cheaper, so the sales department must sell the rhombohedral form"—completely disregarding the fact that the consuming industries have very sound reasons for demanding the monoclinic form and will not buy the rhombohedral material *at any price* so long as the monoclinic is available.

Too often the research engineer, casting around for a new product, will see that "X" is selling for $10.00 per pound. He estimates he can make it for $1.00. The apparent margin looks attractive and he goes ahead completely ignoring the fact that the market for "X" may be only a few pounds per year. Too often the volume factor is neglected. Note that total profits usually increase with volume, *even though the unit margin between cost and selling price decreases.*

Instead of seeking to make products with a high unit margin of profit, the development engineer will usually make more total profit for his employer by seeking those products which have a very large market potential.

Too often the chemical engineer in industrial development work disregards market economics to his sorrow. Too frequently is it assumed that product X, Y, or Z can be sold simply because it can be made cheaply or because its disposal by sale will cure a production headache.

To the average chemical engineer in industry, chemical merchandising is merely a matter of entertaining customers and booking orders. Actually chemical merchandising today is an engineering job, and engineering methods can be and are applied to it.

The post-war chemical engineer must have a broader knowledge of the industry he is to enter. He will know his engineering, his unit processes. But will he have any idea of the way his industry operates? Will he see the chemical industry as a

whole from raw material through to final profit, or will his view be that of a series of partially related unit processes?

The chemical engineer in industry has acquitted himself with distinction in the fields of research and production, but I am sorry to say that he has not done too well in the field of management and administration. Too few of our chemical enterprises today are actually headed by chemical engineers.

The post-war chemical engineer will have many opportunities open to him in research, in production, in sales, and in management. What he makes of these opportunities will depend upon his training. I have no fear that he will fail in research or production, but his advance into executive and administrative responsibilities in the chemical industry will demand that he convey his thoughts clearly and forcefully in writing and speech and that he have a sound knowledge of the economics of the industry.

The Scope and Aims of Civilian Aero-Medical Courses and Their Relation to Engineering*

By F. R. STEGGERDA and M. K. FAHNESTOCK
University of Illinois

In discussing the scope and aims of civilian aero-medical courses and their relation to engineering, it would seem wise to examine first the activities of the Army and Navy in this regard. As a result of aerial warfare which must be carried on at altitudes of 20,000 to 30,000 feet, man has been forced to surpass the limits of human endurance; and the flight surgeon has been compelled first to study and then to teach pilot and crew the use of mechanical aids and also what could be expected when the human body was exposed to marked changes in acceleration as well as atmospheric conditions. That the problems were many and difficult to solve was soon apparent, but after a concerted effort on the part of physiologists, psychologists, physicists and engineers, it seems safe to say that in the last five years greater advancements have been made in our aero-medical knowledge than would normally have happened in 40 or 50 years of peace time. That the activities of the Army and Navy have pointed the way for the future of civilian aeronautics is obvious, and a tremendous increase in civilian interest makes it necessary that considerable effort be directed toward the solving of their problems. Although we have no knowledge of the intentions and aims of the Civilian Aeronautics Administration, which governs these problems, it would seem to be quite within the scope of our topic to inquire into the requirements for the civilian pilot's license under its jurisdiction and also point out the advisability for a period of training in aero-medical problems similar to those required by the military personnel.

An examination of a little booklet put out by the C.A.A. points out that the requirement for a civilian pilot's license is to pass examinations in (1) civil air regulations, (2) navigation, (3) meteorology, and (4) general servicing and operating of aircraft. In the light of these requirements and the marked advances made in the field of aero-medical sciences, it seems apparent that there is a conspicuous lack in that the pilot is not required to know something about the limits of his own body capacities when exposed to various atmospheric conditions.

Just as in the Army, there seems to be no great need for concern in this respect for the supervision of the commercial airline pilots and crews; but it is the owner and flier of the private plane, who works for no one and is responsible to no one but himself, who should be guided and, if necessary

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controlled. It would be futile to expect that a "thou shalt not" would keep the civilian pilot, flying his own plane, from exploring the unknown and forbidden territories, unless he has a definite knowledge of the consequences and is taught how to guard against them.

If we accept this as an essential problem, is it not logical then to require that the pilot, as well as any others who may be immediately associated with aeronautical problems, have a certain amount of training along these lines before he is given the right to take a plane off the ground? This surely would be more sensible than to have him suffer such unexpected experiences as a blackout, severe abdominal pains, or loss of consciousness.

As to how a program of this sort should be conducted is rather difficult to say, but it would seem that just as in the case of the military, an attempt should be made to familiarize the medical doctor to be conversant with the research and findings of the government and certain commercial airlines, and in turn be available to help organize and teach the civilian pilots and their associates so that in the future expansion of aeronautics there will be fewer accidents to mar and hamper the progress of this industry. Such a program could well be facilitated by preparatory courses in physiology both in high schools and colleges to acquaint the future pilot with some of the fundamentals of body function.

That the path through which such a civilian program will have to travel before it functions satisfactorily will be different from that taken by the Army and commercial airlines is obvious, because in the case of the Government and commercial airlines the officials in charge set up the requirements for their employees; and if these fail to pass the necessary physiological and psychological examinations for physical fitness, they fail to get the job, whereas, in the case of the private civilian pilot, the only party concerned is the pilot himself. He wants to fly the plane only for the joy and satisfaction it will give him and not necessarily for any professional reasons. Therefore, one can readily see that the standards for training must be much less rigorous than for the professional flier.

What are some of the principal concepts that should be put across to the public regarding their body functions if this policy is found feasible? It would seem that the major problem to start with would be to convince the civilian that his body is made up of a number of functioning systems such as the heart, lungs and brain; that these in themselves show wide ranges in function; and then to point out that all of these systems function together to adjust against various physical strain and stresses. With such a background he should next be thoroughly acquainted with the effects the atmospheric conditions at various altitudes will have on the body and the limits of body adjustment under these conditions. Such training will help him to recognize and understand some of the following problems:

1. At 10,000 feet the temperature is −4.8° C.; and no matter how much clothing he may wear, his body cannot be protected against heat loss indefinitely.

2. He will understand that at 10,000 feet within a short time the oxygen saturation of the blood is approximately 85 per cent of normal and that this is the lower limit for normal body function in most individuals.

3. He will understand that at 10,000 feet the atmospheric pressure is approximately ⅔ of an atmosphere and that under such conditions gases within the body will expand and may cause discomfort in the gastro-intestinal tract.

4. With sudden changes in acceleration there will be a sudden shifting of the blood in and out of the head which may cause a black- or red-out along with a loss of consciousness.

5. He will understand why air-sickness is associated with certain motions and vibrations and how it is associated with a lack of coördination between the eye and the ear.

6. He will understand why rapid descent from altitude will cause violent pains in the ear and sinuses and how to guard against it.

7. Oxygen deficiency may manifest itself in a feeling of self-satisfaction and over-confidence, very similar to the sensations which accompany intoxication.

8. He will understand why certain symptoms will come on more quickly in persons suffering from a partial physical deficiency.

9. He will understand why fatigue, anxiety and alcohol will have a marked effect either temporarily or permanently on his ability to adjust to certain environmental conditions.

10. He will understand why flying with infectious colds may lead to serious ear and sinus infections.

11. He will understand why the Army and Navy never allow their pilots to ascend to altitudes above 12,000 feet without oxygen.

In short, if the civilian flier has to know about the traffic rules of the air, the nature of the winds and atmosphere, as well as the mechanics of the plane he flies, why should he not know the essential facts about the human body which are responsible for the proper functioning of all of these things? It would seem that in the future an examination requiring a knowledge of the fundamentals of body function is just as essential as those now used by the C.A.A. It would seem desirable that after this is accomplished, an educational program concerning new developments should be promoted. It is agreed that such a program may meet with objections and will be hard to be made effective. We will always have the "One-way Corrigans," many of whom will be less fortunate that he was, but surely the average American who wants to fly for the sake of flying will gladly submit to such a type of training, both for himself and others.

While some few engineers connected with aviation accuse the medical people of overdramatizing the importance of the physiological and psychological problems involved in flight, and for the development of the thought that only "Supermen" can fly, the majority now recognize that such an accusation is unfounded, and that especially in military aviation the end performance of aircraft in combat is finally dependent upon the efficiency of the crew as well as upon that of the mechanical machine. Thus, it is now accepted that the problems presented in military flying necessitate the full understanding and cooperation of engineers, physiologists and psychologists.

While civilian flying does not normally present the extreme factors of altitude, temperature, acceleration, and fatigue with their accompanying physiological stresses and adjustments, it is complicated by the character and diversification of the personnel and the

economic limitations of the aircraft and equipments involved. People of all ages and degrees of physical impairment desire to fly. They have the inherent right to do so, unless it threatens their safety or that of others. The future of the aircraft industry depends largely upon the ability of engineers to provide inexpensive, reliable and simple to operate aircraft for this mass of potential personal fliers. They must fit the machines to certain economic and personnel limitations. This does not mean that the aeronautical engineer must be a trained physiologist or psychologist, but it suggests that he be sufficiently informed to be aware of the need for recognizing the physiological and psychological problems, and for coöperating with those properly trained to help solve them.

The Utilization of Industrial Reference Material in Aeronautical Engineering Training*

By M. J. THOMPSON

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Formal college training in the field of aeronautical engineering is approximately thirty years old, at least in the United States. It has had various and sundry growing pains during this period, to which the proceedings of this society, particularly during the last few years, bear ample witness. This situation requires no apology, in fact it is rather one of which we may be proud, since a field of education which considers itself as having reached the zenith of perfection is probably not far from, if not already in a state of acute senility.

During the period beginning with World War I, we have seen the airplane develop from a fabric-covered stick and wire framework, through the welded tubular steel construction to the present all-metal stressed-skin structures. In the early days drag in flight was considered as entirely of the eddy making type, proportional to the square of the velocity, and skin friction drag was considered of negligible importance. Today the situation is almost completely reversed. Eddy making drag, when present, is considered an indication of faulty external design, while much attention is given to ways and means of reducing the remaining skin friction component. The aerodynamic laws which govern flight in the sub- and super-sonic ranges of high speed are not yet completely known, but their increasing importance is fully realized. Recent developments indicate that some rather radical changes in aircraft propulsive systems await us in the not too distant future with the introduction of the gas turbine and the use of jet propulsion, at least in certain types of aircraft.

Regardless of the viewpoint one may take concerning the proper division of emphasis on "fundamental" and "applied" subjects, it is apparent that any engineering curriculum which may be properly considered as aeronautical in character, must be maintained as flexible as possible, both as regards its over-all organization and its individual courses. The progressive instructor then faces the problem of maintaining a fresh point of view in the work which he presents to his students and in keeping up to date with at least the broader trends and developments in industry. This problem is further aggravated by the fact that we have not to date enjoyed an over-supply of outstanding textbooks in the aeronautical engineering field. In fact in some lines we have had no books at all until only recently. Thus the instructor must do a great deal of organizing and planning

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of a large amount of rather heterogeneous material in order to develop a satisfactory course which may be presented in a systematic and lucid manner. Certainly the problem is quite different from that of the instructor in the older and more completely established fields, such as engineering drawing, applied mechanics, and mathematics. Even in the more specialized fields, such as civil, mechanical, and electrical engineering, this difference is found to a certain degree. It is not to be implied from these comments that courses in these older fields are so completely perfected that the instructor need only repeat himself year after year in a parrot-like fashion. This is bad teaching under any circumstances. It does not seem out of place, however, to call attention to some of the special difficulties which face the aeronautical instructor.

In endeavoring to build up a sound and progressive body of material for his courses in aeronautical engineering, the instructor may use advantageously a large amount of reference material which might be called industrial in character. For the present discussion, this might be considered to include such items as industrial drafting and design manuals, standard parts books, equipment and materials handbooks and catalogs, as well as numerous representative drawings and problems illustrating industrial practices and applications of fundamental principles. Another group of items would include the handbooks and technical reports of the military services, particularly the research and development sections, along with the many valuable technical reports issued by the National Advisory Committee for Aeronautics and the Civil Aeronautics Administration. This list could be expanded to several times this size, but the items shown above are sufficiently representative to indicate the type of material which is under discussion.

It is probably immediately obvious that a considerable amount of careful selecting and planning must be done by the instructor in effectively using this material, if for no other reason than the fact that there is so much available. Furthermore, the engineering college cannot follow the practices and procedures of any one airplane company exclusive of all others. This, however, is not too serious a problem in the case of drafting room practices, since they do not differ between companies by such great amounts that a representative and coördinated sampling of all of them cannot be readily presented. Another approach which can be used effectively, where a student establishes an early relation with a particular company, is to provide him with as much of the reference material of that company as he can effectively use in his design courses and other related subjects. This plan, of course, usually requires that the student make his industrial contact not later than the early part of his senior year.

A danger incident to the use of industrial reference material which must be carefully guarded against is for the instructor to become so involved in the details of a particular calculation or design procedure that the student completely forgets about the fundamental principles involved. It is of no great value to the student to know that in solving a spanwise load distribution problem, Company "A" "adds to column 1 to column 2, multiplies by column 3, and divides by column 4", while Company "B" "divides column 3 by column 4, adds columns 1 and 2 and then multiplies by the first quo-

tient." This, perhaps, is not the best of examples, since the undergraduate engineer should not be too greatly concerned with spanwise load distribution problems in the first place. If he is, he undoubtedly has the all too prevalent and mistaken idea that he can enter industry directly as an aerodynamicist or stress analyst without a satisfactory apprenticeship of detail and layout design experience, supplemented in most cases by graduate study.

Catalog and handbook material which is largely informative in nature and not too directly connected with fundamental theories, should be introduced only to the extent that it will enable the student to become familiar with its character, to know where such information may be found when he needs it, and to learn how to apply it. To be most effective, the instructor should see to it that it is kept up to date and it is reasonably well indexed in a usable form. Otherwise the material will be thumbed over once and then thrown in a corner of the drafting room, where it proceeds to gather dust.

In making use of industrial reports of a technical character, careful attention must be given to the problem of correlating them with the fundamental theories being studied and introducing them at the proper time as appropriate applications. The student's background of work already completed must be carefully examined so that the material he is given along these lines is not completely over his head.

The purist in engineering education may be ready by this time to raise a great hue and cry that all this represents a trend toward overspecialization. In this connection, it might be worthwhile to consider briefly one or two points which bear directly on this discussion. We hear a great many expressions of opinion to the effect that an undergraduate engineering program should emphasize the fundamental subjects of drawing, mathematics, mechanics, thermodynamics, and so on, and should not make any major attempt to carry the student into such advanced problems as aerodynamics and structural analysis. I am thoroughly in agreement with this general philosophy, but I wonder if there is not a danger of carrying this idea too far. Should we not give some consideration to what we really mean by our classification of "fundamental" and "applied" subjects? Instructors in some of the older fields of engineering are often prone to look upon their subjects as fundamental where actually the only real basis for that opinion lies in the fact that these topics have been included in engineering curricula for the past fifty years. I can see nothing more fundamental in a problem in the theory of structures which involves the analysis of a bridge truss or a reinforced concrete beam, than one which deals with an airplane wing spar or a landing gear structure. As a matter of fact, the aircraft problem may often involve the more complete and rational application of analytical methods and fundamental theory. Certainly there is no difference in the fundamental principles involved in the study of a flap control mechanism and, say, that of an automatic bottling machine or the valve mechanism of a steam engine. Thermodynamic principles can equally well be applied to the study of aircraft cooling, heating and ventilating problems as to the detailed study of the operation of a Corliss engine.

It might be said that our most widely used fundamental concept in mechanics is that of a vector, which fundamentally

is a quantity having direction, magnitude, and sense. As soon as we call that vector a force or a velocity, are we not dealing with applications? I doubt very much, however, if we would like to recommend that our work in applied mechanics begin with a formal course in vector analysis.

It seems to me that the real point involved here is that actually what we teach in engineering courses should be a combination of fundamental theory and judiciously chosen applications in the field of the student's major interest. These two aspects should be carefully balanced so that the student may acquire from his training a knowledge of fundamental principles, the ability to apply them in practice, and a knowledge of current practices in his chosen field. The first point has already been discussed. The second one we teach by showing the student selected examples of how fundamental theory has already been applied. Industrial reference material is of value here but more particularly in connection with the third point. By the use of such material, I believe we can maintain the desirable features represented by the first two points and at the same time train a student to become more immediately productive after his entrance into industry.

Random Ideas in the Teaching of Chemical Engineering*

By G. W. GLEESON

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It is common practice among teachers of chemical engineering subject matter to devote some time to the study of the personal characteristics of the students. Results of such study might be expressed at some length; however, B. F. Dodge in the preface to his recent book, "Chemical Engineering Thermodynamics," sums the characteristics in a single adjective when he refers to the average engineering student as a "pragmatic individual." To save a trip to the dictionary and to permit exclusion of those connotations which are obviously not applicable, the term "pragmatic" infers that the engineering student is practical, matter-of-fact, concerned with practical values and consequences, and definitely interested in the interrelation of events or subject matter. The single word "pragmatic" is descriptive of a large part of the personality of the average "chemical engineer," but there must be added two additional personal attributes; precociousness to a varying degree, and a certain sensitiveness which responds to changes in surroundings and conditions.

It is not the purpose of this paper to dwell upon the personal characteristics of students. An attempt will be made to present a few random ideas and opinions on teaching and to describe a few practices which are certainly not new or original with the writer, but which merit discussion. It is considered significant that many, if not most, of the teaching procedures which have been widely adopted are in harmony with student character. Perhaps, this harmony has been in large part responsible for the evident successful teaching practices of the past, and, certainly, indicates that we should be very critical in our analysis of the many "modified" practices proposed for the future. In speaking of these modified practices, let us be sure that we make a careful distinction between "training methods" and "educational methods"; let us remember that our educational procedures of the past have had as an objective the development of initiative and the capacity for independent thought. The latter objective is far more difficult of attainment than routine training to accomplish a repetitive task.

In the following discussion, no particular attempt will be made to emphasize the relationship between personal characteristics of the average student and the topic under discussion. Sufficient to say that each topic to a large or small degree reflects student attitude or is directly related thereto.

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The Problem Method

The problem method of teaching is not a new topic. It is so familiar to those who teach chemical engineering that I would hesitate to mention the subject except that I am convinced that within the method lies the essence of engineering. The method is in accord with student character; it accomplishes the teaching objective; it provides mental associations which facilitate memory; it provides opportunity for integration; it eliminates the non-essentials; it expands student ego; it develops initiative; it promotes self-reliance. Certainly any method so inclusive deserves expansion to the widest degree.

I am not going to dwell upon details of the problem method of teaching which should perhaps be referred to as the "situation method." President R. E. Doherty at the Carnegie Day exercises in 1940 said all that needs saying. My copy of the reprinting of his address as it appeared in the November 1943 issue of the S.P.E.E. JOURNAL is marked and remarked. Indeed, I consider it a remarkable presentation of the basic philosophy of engineering education; hence, the remark that the method should be extended to its full usefulness in the manner and as outlined by President Doherty is in order. I quote a single pertinent sentence, "The test for identifying a cultivated mind is to face it with perplexities—to face it with new situations not in the books but involving principles and knowledge which the mind has studied."

Problem Standards

The "situation method" of teaching normally results in extensive written assignments, usually the solution of problems. Let no opportunity for development pass. Problem composition and standards are important, not each exercise in itself, but four years of consistent adherence cannot fail to establish a pattern of neatness and order that becomes a part of student character. From the freshmen year on, insistence upon an established standard of written presentation and refusal to accept anything less contributes to orderly thinking, promotes pride in accomplishment, and conserves the time of both student and instructor. I mention that such problem standards include selection of paper, consideration of margins, use of simple instruments in drawing all lines and sketches, lettering rather than long hand, proper indexing and paging, consistent use of standard nomenclature, and many other minor items. Briefly, the objective of the standard might be the approximation of those practices incorporated in any good textbook.

In passing, I remark that four years of practice in the art of lettering produces remarkable results. The freshmen gripe; the graduates express their thanks.

Grading

We will not argue the merits or weaknesses of grading systems. Most instructors are required to submit grades. It has always been my conviction that at all times the student should be fully aware of his comparative standing in the class. Students like to have some index by which they may gage accomplishment. Such an index should be simple, quickly comprehended, and flexible. Some years ago the writer started a system which has served his purpose so well that perhaps it deserves a brief description. It is simple in the extreme. Each as-

signment is accorded a number of points, depending upon the complexity and importance. A student is credited all possible points for a fully satisfactory solution (including promptness and adherence to standards). Anything less than a complete solution earns partial credit. When papers are returned, they are plainly marked 5/8 or some such a number indicating 5 points earned out of a possible 8. At any time a student can total the earned and possible and arrive at his percentage. From time to time during the course, the median percentage for the class is announced. The students appear to be fully satisfied with this simple bookkeeping.

In the grade book, there is recorded along with the student earnings in each exercise an index letter which indicates that the exercise is a home assignment or a class quiz. We have never objected to the students working together outside of class if that work is honest and the weak do not lean too heavily on the strong. Class work is entirely independent. At the end of the term, all outside points and all class points are totaled separately. Class points are then plotted vs. total points, and a lineal distribution results. It is surprising how consistently the students group themselves along the line in such fashion that it is not at all difficult to segregate into various grade categories.

Note that the procedure is very flexible and adaptable to assignments of varying importance. Note also that the plot gives double the weight to class work as to homework. You can be sure that the student who falls off of the lineal distribution hears about it. He represents the weak leaning on the strong or else has exceptional ability to earn credit in class quizzes without doing home problems. (There are but very few of the latter.) Note also that the system is essentially objective in nature. Above all, it is simple, and I presume "educationally" unsound, because it serves its purpose so well.

Social Science

The title to this paper carried the work "random"; hence the writer is relieved of any continuity. It is considered that a few remarks on social science studies might as well be included here as elsewhere.

Someone has said that "the education of an engineer begins in the home and continues throughout his life." I have had occasion to question the general applicability of the statement at both ends. Many students come to college with no visible evidence of a consistent home training. In fact, in instances I question if even the most extensive broadening of our technical curricula to include the maximum of social science and the humanities would serve to overcome the inadequacy of background associations and training. Likewise, examples of overtraining along certain lines are frequently evident. Many students have developed strong social complexes before they reach college. Also, although I do not like to admit it, there may be much significance in the widely publicized story of the campus dog.

I should also remark that for some long time in the past and emphasized at present, the engineer and the scientist have been accused of lack of responsibility to society for their discoveries, scientific inventions, and technical developments.

We are, I believe, fully aware of the desirability of including more of the cultural and socially significant studies in our engineering curricula, but I believe the time has come when we must

exercise some control as to what is taught in these studies. I am of the opinion that the tenets laid down in the S.P.E.E. Report of Committee on Aims and Scope of Engineering Curricula (S.P.E.E. JOURNAL, March 1940) as regards the humanistic-social studies should be more widely recognized and adopted. I venture to repeat the suggestions.

"1. Understanding of the evolution of the social organization within which we live and of the influence of science and engineering on its development.
"2. Ability to recognize and to make a critical analysis of a problem involving social and economic elements, to arrive at an intelligent opinion about it, and to read with discrimination and purpose toward these ends.
"3. Ability to organize thoughts logically and to express them lucidly and convincingly in oral and written English.
"4. Acquaintance with some of the great masterpieces of literature and an understanding of their setting in and influence upon civilization.
"5. Development of moral, ethical, and social concepts essential to a satisfying personal philosophy, to a career consistent with the public welfare, and to a sound professional attitude.
"6. Attainment of an interest and pleasure in these pursuits and thus of an inspiration to continued study."

I also venture a personal opinion that social studies might very well include as texts such books as "The Scientific Life" by J. R. Baker or "The Social Function of Science" by J. D. Bernal. In this connection, "what is good for the goose is good for the gander." Liberal arts students and education majors might well profit by a better understanding of the history and socially significant contributions of science and engineering.

So much for social science. If we are to base our expectations of the future on our experiences of the past, it appears reasonable to conclude that the social science studies as they have been presented to the engineering student must undergo some change if they are to accomplish their purpose and answer the criticisms which have been directed at the profession. This revision might well be in a direction more compatible with student character and more in harmony with the stipulated objectives.

Background

It appears that each year the students from high school arrive with less and less background preparation for study in the field of engineering. The writer's observations in this connection have been verified by others in various sections of the country. In fact, a review of high school offerings indicates that even if they desired to do so, students in many schools could not satisfy minimum requirements. The subjects are not taught. It would appear that the period in which lower division educators preached that "the social significance of mathematics can be taught in one hour" is at an end. It is only reasonable to hope that the engineering profession with unanimity of purpose will insist upon proper guidance at the high school level and the provision of adequate courses taught by someone else than the physical education instructor. Our greatest opportunity to broaden the base of our technical curricula and include a larger complement of humanistic-social studies is through time saved in the

presentation of fundamental subject matter at the elementary level.

So-called "progressive education" is on its way out or ought to be. Fundamental education at the lower levels which leads to both scholarship and discipline must be restored. It is much more difficult to correct an improper start than to start properly. We should be done with the necessity of spending time on the development of those student attributes which should have been fostered in high school. The ambiguous objectives of high school curricula should be clarified, simplified, and harmonized with the requirements of the times.

Integration

Chemical engineering education is concerned with the development of an attitude of mind. Education has been accomplished only when a student has the ability to apply fundamental knowledge to a new situation, fictitious or otherwise, in a straightforward and logical manner. This ability is acquired through practice and infers the problem method of teaching. It is considered that current practices are quite satisfactory, but there appears to be no logical reason why such practices should not be extended to a greater degree. In the usual case, when the student studies mechanics, he solves mechanics problems; mathematics, mathematical problems; thermodynamics, thermo problems. This is as it should be. However, there exists the necessity of a course at or near the terminal level where any and all basic subject matter should be integrated. Some institutions provide such integration, but the practice is by no means universal.

The writer considers the senior-year course in chemical plant design as the logical place for such integration. At this point, the student can be faced with perplexities which involve any and all of the fundamental subjects which he has studied. The student contest problems were a big step in this direction and were included as a part of many courses. It is not difficult to formulate a design problem in which the unit operations, chemical kinetics, and thermodynamics are integrated with the application of the principles of mechanics of materials, economics, industrial electricity, etc., all to be approached by methods which are essentially mathematical. The interrelationships of fields of subject matter can then receive proper emphasis.

In connection with such an integrated course, the writer has over the past ten years received a more favorable student reaction than in any other teaching with which he has ever been identified. Accordingly, a few suggestions regarding such a course are made.

1. The course is not designed to emphasize anything "new" but rather presents an opportunity to apply that which is already known (presumably).
2. Each exercise is designed to integrate, and require the knowledge of several fields of subject matter. It is not uncommon to include a field of subject matter with which the student is only superficially familiar.
3. Responsibility is placed entirely on the student. It is his problem and the method of approach, presentation, degree of completion, and all decisions rest entirely in his hands. He must display initiative.
4. The instructor (in so far as the problems or assignments are concerned) acts to no greater capacity than that of a division chief or in-

mediate supervisor. Questions are freely answered and suggestions made, but no definite pattern is laid down for the student to follow.

5. Time limits are imposed.
6. All available physical facilities for calculation, reproductions, etc. are placed at the disposal of the student.

You will find no dearth of subject matter for discussion in connection with an "integrated" course. In fact, the time is usually far too short to cover all points of discussion raised by the students themselves. It is a difficult course for the instructor as well as for the students, but I am convinced that the results merit the effort.

Unconscious Transfer

Regardless of the many remarks to the contrary, students do tend to adopt the pattern of activity of their teachers if such appeals to them. This is especially true in the case of longer associations with major professors. Real friendships might be expected to effect some transfer of philosophy and methodology. Teachers should take advantage of this simple fact. Each graduate, when he departs, takes with him some part of the makeup of each of his teachers to a greater or lesser degree. The attributes of the teacher rub off on the student. Students tend to ape those whom they respect.

May I say that in the prewar brand of senior year love affairs where marriage was indicated, a very few words to the student by the professor on the responsibility to wife and family would sell more insurance than all of the salesmen combined. A few chance remarks about correspondence and letterheads, and the printer commented upon the sudden increase in business. Much can be effected by suggestion and the transfer is painless; indeed, it is fun.

Speed

I have always choke-fed students in so far as assignments are concerned. Objections by the students to the procedure are answered by explaining that there will always be more work than even the best student is expected to accomplish, and that sometime the student must be given opportunity to exercise judgment and allocate his time accordingly. The responsibility is placed upon the student, and I have never attempted the impossible procedure of limiting the extent of the assignment to the average ability of the class. I admit the several evils of the practice; however, I am convinced that the advantages far outweigh the disadvantages. Even after seventeen years, I am still surprised at the capacity which students can develop if allowed to do so in their own way. Difficulties are experienced in the first two years, but the classes appear quite willing to accept the system after it has been explained to them. Real competition develops in the junior and senior years, and ability, particularly to solve problems, develops accordingly. I have often wished that someone had inflicted the practice upon me.

Things

Perhaps this is somewhat philosophical. It is not necessary to know detailed information to have a well rounded education. Just to know that things exist and appreciate their existence is a first big step in general educational development. Students from high school are rudely shocked when they find that instead of the usual statement that "they must read three fiction and two non-fiction books dur-

ing the year," they have four years and should read the library. This is not a requirement, it is only a suggestion. Literally, it could not be done, perhaps in their lifetime, but the suggestion is still a good one and serves to introduce a discussion of procedures of scanning, of following material coming to the new book table, and of reading in diverse fields.

Conclusion

This presentation has been extended far enough. The ideas are certainly "random." They do not form any pattern from which conclusions may be drawn; hence, this heading is used to include one departing thought.

I am proud of all engineering as a profession and of the record of the persons in it. To the many who direct criticism at the engineer and his accomplishments, I pose this question. "Can you name a profession which has accomplished more for civilization and which at the same time has remained entirely ethical in its relationship to society?" I repeat, "The technical terms of science rather than quotations from the classics have come to be recognized as the hallmark of an educated person."

A Placement Examination for Mechanics*

By W. E. WILSON
Armour Research Foundation

An objective type placement examination which may be used to predict the performance to be expected of students in engineering mechanics is described in this paper. The examination is discussed from the standpoint of its purpose, type of question used, actual use to date, and possible future applications. An analysis of the effectiveness of the examination is indicated by the performance of students who took the examination and then pursued a standard course in engineering mechanics is given.

Purpose of the Examination.

This examination was conceived following the writer's experience with several groups of students in engineering mechanics who came to the course with the usual qualifications of credit in mathematics and physics. It was found all too frequently that a creditable performance in mathematics and physics as indicated by passing or even honor grades was not followed by passing work in engineering mechanics. It was deemed desirable to divide the classes into sections rated "fast" and "slow" and once again it was found that the available grades in the prerequisite courses were inadequate for the purpose.

A comprehensive study was made concerning the correlation of grades of students in their prerequisite courses and their performance in mechanics. The overall picture was frequently not unreasonable in that the coefficients of correlations were not too low. However, certain notable discrepancies especially related to extraordinarily poor performances of students whose work in mathematics had been highly rated were disturbing elements.

It appeared from an analysis of certain cases that it might well be possible for a student to learn certain techniques in mathematics which would enable him to attain a high grade in mathematics and yet leave him with a total lack of understanding of fundamental principles. With this in mind it was decided to set up an objective type examination which would serve the dual purpose of evaluating the student's preparation in mathematics and physics and predict his performance in mechanics.

In order to attain the first objective the examination would necessarily have as its subject matter the principles, facts, and techniques of mathematics and physics. In order to attain the second objective it was felt that it would be necessary to use questions of such a type that the student would find it necessary to exercise his ability to reason out a problem with which he had not previously been confronted. An effort was made to attain these

* Presented at the 52nd annual meeting, S.P.E.E. (Mechanics), Cincinnati, June 22–25, 1944.

objectives with the success described in the following discussion.

Description of Examination.

The examination which evolved through a period of about two years use contains thirty-five questions of which thirty are of the multiple choice type and five are of the completion type. The first draft contained but thirty questions and covered the topics of algebra, trigonometry, differential calculus, and physics. It was found necessary after using this examination to revise a number of questions and it seemed desirable to add some in integral calculus. The final draft contains ten multiple choice questions on trigonometry and algebra, ten on physics, ten on differential calculus and five completion type questions on integral calculus.

The actual subject matter in each category covers those fundamental facts, principles, and techniques which appear to be a necessary part of the equipment of a student embarking upon the study of engineering mechanics. These questions are shown herewith in Table I. The questions have been used several times and were revised when an analysis of their difficulty and selectivity indicated the necessity for such change. However, it appears that there is need for further revision, as will be pointed out in the subsequent analysis.

Administration of Examination.

It was the practice when giving this examination to use it at the first meeting of the class. No previous announcement was made, and it was generally true that the students made no special preparation for the occasion. It is not necessary to follow this practice, but uniformity of results may be expected only if the degree of preparation by the students on various occasions is comparable.

The method employed in the grading was finally established as follows. Since the multiple choice questions presented five choices, it was concluded that there should be a deduction for incorrect replies to discourage indiscriminate guessing. If a student were to guess on all questions it is to be expected that he would answer one in five correctly. Under these circumstances four out of five replies would be incorrect and a deduction of one-fourth of the number of incorrect replies would result in a score of zero as would be desired. The multiple choice questions were therefore graded by counting one point for each correct answer and deducting one fourth point for each incorrect reply. If the student failed to answer a question the score on that question was zero.

The completion type questions which cover integral calculus presented a somewhat different problem in grading. No possibility of choosing existed, hence no correction to discourage guessing was necessary. However, a number of students gave the correct form of the integral but neglected to include the constant of integration. In such cases half credit was given. It was, therefore, possible for a student to receive a grade of zero, one-half, or one on each of the completion questions.

Analysis of Results.

The meaning of the performance by students on the examination has been analyzed on the basis of the following points:

1. Correlation between the examination grade and the grade in the course.
2. Selectivity of the questions.
3. Difficulty of the questions.

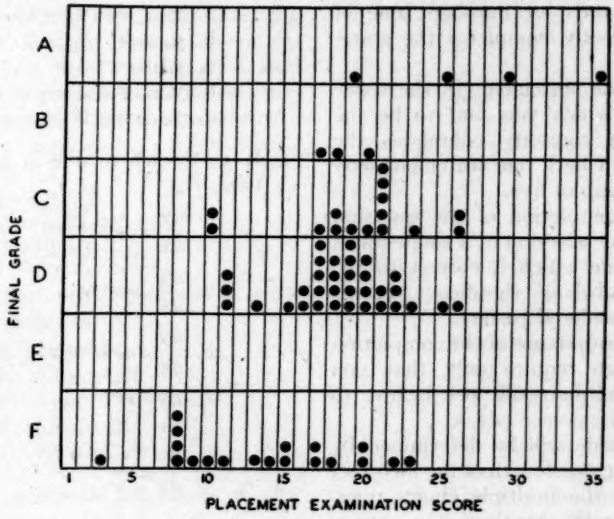

FIG. 1

4. Predictive value of examination.
5. The examination in evaluating training in mathematics in physics.

For the purposes of this study the performance in both the placement examination and a course in mechanics of seventy-four students was studied. These students were in three sections of a course in engineering mechanics. The course covered both Statics and Dynamics in a single semester with four meetings of the class per week. Each section had a different instructor.

The correlation between the course grade and the grade on the placement examination is shown in Fig. 1. In this chart the performance of each student is indicated by a point, the coordinates of which are the two grades. It will be observed that the grade E, a condition, was not given. This conforms to a long established departmental policy which frowned on this grade. As a consequence, it is probable that some students received passing Ds and some failing Fs, although a straight numerical grade average would have indicated Es for them.

For purposes of analysis, the following numerical equivalents were assigned to the letter grades: A—5, B—4, C—3, D—2, E—1, F—0.

The significant statistical data for the grades are as follows:

Placement examination:
Average Grade—18
Standard Deviation—5.4
Final course grade:
Average Grade—1.92
Standard Deviation—1.36
Coefficient of correlation—0.55

TABLE I

MECHANICS PLACEMENT EXAMINATION

This examination is partly of the multiple choice type, partly completion type. Each of the multiple choice questions consists of an incomplete statement and five clauses,

phrases, words, or numbers, one of which correctly completes the statement.

Check the statement, in the space provided, which you find to be the one which correctly completes the sentence. Check one statement *only* in each group of five.

If the completion of the question requires the selection of a single number, the one which is correct to the given number of significant figures will be considered correct.

Five questions are of the completion type, which require only that you write down the result you believe to be correct.

Your grade will be determined by subtracting one-fourth of the incorrect replies on the multiple choice questions from the total of the correct replies. Judicious guessing is wise but wild guessing will materially lower your grade.

1. If the equation of a curve is $y=x^3=2x^2$ the angle θ between the x-axis and the tangent to the curve at the point at which $x=2$ is given by:

   .....a. $\tan\theta=0.25$
   .....b. $\tan\theta=1$
   .....c. $\tan\theta=4$
   .....d. $\tan\theta=0.50$
   .....e. $\tan\theta=0$

2. The tangent to the curve described by the following equation coincides with the y-axis at the origin:

   .....a. $y=x^2$
   .....b. $y=ax^2+bx+c$
   .....c. $y=a\sin x$
   .....d. $y=a\sqrt{x}$
   .....e. $y=a\cos x$

3. If $y=3x^2-6x$ the minimum value of y is:

   .....a. $y_{min.}=-9$
   .....b. $y_{min.}=9$
   .....c. $y_{min.}=3$
   .....d. $y_{min.}=-3$
   .....e. $y_{min.}=0$

4. If $y=e^{ax}$ where a is a constant, then

   .....a. $\frac{dy}{dx}=ae^{ax}$
   .....b. $\frac{dy}{dx}=e^{(ax-1)}$
   .....c. $\frac{dy}{dx}=ae^{(ax-1)}$
   .....d. $\frac{dy}{dx}=\frac{e^{ax}}{a}$
   .....e. $\frac{dy}{dx}=e^{ax}$

5. If $y=A\cos Bt$ where A and B are constants, then $\frac{dy}{dt}$ is:

   .....a. $-A\cos Bt$
   .....b. $-AB\cos Bt$
   .....c. $-AB\sin Bt$
   .....d. $+AB\sin Bt$
   .....e. $-A\sin Bt$

6. If $y=x\sin x$, then $\frac{dy}{dx}$ is:

   .....a. $x\sin x+x\cos x$
   .....b. $-x\sin x+x\cos x$
   .....c. $-x\cos x$
   .....d. $\cos x\,dx$
   .....e. $x\cos x+\sin x$

7. If s is the distance which a particle has moved on a straight line from a fixed point in the time t and $s=+at-bt^2$, then the velocity v at any time is given by:

   .....a. $v=a+2bt$
   .....b. $v=a+2b$
   .....c. $v=at-2b$
   .....d. $v=a-2bt$
   .....e. $v=at^2-bt^3$

8. The velocity of a point traveling on a straight line is given by $V=At^2+Bt+C$, where A, B, and C are constants and t is the time. The acceleration at time $t=4$ is:

.....a. $8A+B$
.....b. $2A$
.....c. $4A+B$
.....d. $16A+4B$
.....e. $2A+B+C$

9. The derivative of $A \sin^2 Bt$ with respect to t is:

.....a. $A \cos^2 Bt$
.....b. $AB \cos^2 Bt$
.....c. $A \sin Bt+B \cos Bt$
.....d. $AB \sin Bt$
.....e. $AB \sin 2\,Bt$

10. The point of inflection of the curve described by $y=\frac{x^3}{3}+\frac{x^2}{2}$

.....a. $x=-3/4$ $y=9/32$
.....b. $x=-3/2$ $y=0$
.....c. $x=0$ $y=-3/2$
.....d. $x=1/2$ $y=1$
.....e. $x=-1/2$ $y=1/12$

11. The tangent of 135° is:

.....a. $+1$
.....b. $+0.707$
.....c. -0.707
.....d. $+2$
.....e. -1

12. If the $\cos\theta=1/3$, the $\sin\theta$ is:

.....a. $2/3$
.....b. $2\sqrt{2}$
.....c. $2/3\sqrt{2}$
.....d. $\sqrt{2/3}$
.....e. $3/2$

13. If the $\sin x=\frac{3}{5}$ and $\cos x=\frac{4}{5}$, then the $\sin 2x$ is:

.....a. $\frac{6}{5}$
.....b. $\frac{8}{5}$
.....c. $\frac{12}{25}$
.....d. $\frac{24}{25}$
.....e. $\frac{7}{5}$

14. The cosecant of an angle is:

.....a. The hypotenuse divided by the side opposite.
.....b. The reciprocal of the cosine.
.....c. The side opposite divided by the hypotenuse.
.....d. The reciprocal of the tangent.
.....e. The side opposite divided by the side adjacent.

15. If the $\sin\theta=0.6$, the $\cos\theta$ is:

.....a. 0.5
.....b. 0.4
.....c. 0.8
.....d. 0.7
.....e. 1.0

16. The sum of $\frac{bx}{a}$ and $\frac{ay}{b}$ is:

.....a. $\frac{bx+ay}{a+b}$
.....b. $\frac{b^2x+a^2y}{a+b}$
.....c. $\frac{(x+y)ab}{a+b}$
.....d. $\frac{b^2x+a^2y}{ab}$
.....e. $x+y$

17. If $\log_e 10=2.31$, then

.....a. $\log_{2.31} e=10$
.....b. $2.31^e=10$
.....c. $\log_{10} 2.31=e$
.....d. $10^{2.31}=e$
.....e. $e^{2.31}=10$

18. If $\log_{10} 2 = 0.301$, then
    .....a. $\log_{10} 8 = 1.204$
    .....b. $\log_{10} 4 = 0.150$
    .....c. $\log_{10} 8 = 0.075$
    .....d. $\log_{10} 4 = 0.090$
    .....e. $\log_{10} 8 = 0.903$

19. A man rows up a stream $4\frac{1}{2}$ hrs. and finds that it requires only $2\frac{1}{2}$ hrs. to make the return trip. If he can row $3\frac{1}{2}$ mph. in still water, the rate of the current is:
    .....a. 1.5 mph.
    .....b. 3.0 mph.
    .....c. 2.5 mph.
    .....d. 1.0 mph.
    .....e. 2.0 mph.

20. The product of $(x^3y^2)^n$ and xy^3 is:
    .....a. $x^{(3n+1)}y^{(3+2n)}$
    .....b. $x^{4n}y^{5n}$
    .....c. $(x^4y^5)^n$
    .....d. $x^{(4+n)}y^{(5+n)}$
    .....e. $x^{3n}y^{6n}$

21. If a ten pound body falls a distance of 10 ft. in a vacuum the kinetic energy
    .....a. Is decreased 100 ft. lbs.
    .....b. Is increased 10 ft. lbs.
    .....c. Is increased 100 ft. lbs.
    .....d. Is decreased 10 ft. lbs.
    .....e. Remains unchanged.

22. A plank 10 ft. long is supported at the ends by knife edges. A weight of 100 lbs. rests on the plank at a distance of 3 ft. from the left end. The reaction of the knife edge at the right end on the plank is:
    .....a. 70 lbs.
    .....b. 30 lbs.
    .....c. 50 lbs.
    .....d. $33\frac{1}{3}$ lbs.
    .....e. 42.8 lbs.

23. A 100 lb. block rests on a frictionless plane inclined at 30° with the horizontal. The force parallel to the plane necessary to prevent the block's sliding down the plane is:
    .....a. 86.6 lbs.
    .....b. 100 lbs.
    .....c. 30 lbs.
    .....d. 50 lbs.
    .....e. zero

24. Newton's first law states that:
    .....a. $F = Ma$
    .....b. Action and reaction are equal
    .....c. Forces are vector quantities
    .....d. The acceleration due to gravity is 32.2 ft./sec.^{2}
    .....e. A body will continue to move with its original speed in a straight line unless acted upon by an external force.

25. A man weighing 160 lbs. is accelerated upward by an elevator at the rate of 16 ft./sec.^{2} The upward force exerted on him by the floor of the elevator is about:
    .....a. 80 lbs.
    .....b. 160 lbs.
    .....c. 176 lbs.
    .....d. 240 lbs.
    .....e. 320 lbs.

26. The moment of a couple consisting of two 30 lb. forces separated by a distance of 2 ft. is:
    .....a. 15 lb. ft.
    .....b. 30 lb. ft.
    .....c. 60 lb. ft.
    .....d. 120 lb. ft.
    .....e. zero

27. If the coefficient of friction is $\frac{1}{3}$, the steepest incline on which a block will remain at rest makes the following angle with the horizontal:
    .....a. $\sin^{-1} \frac{1}{3}$
    .....b. $\tan^{-1} 3$

.....c. $\cos^{-1} \frac{1}{3}$
.....d. $\tan^{-1} \frac{1}{3}$
.....e. $\sin^{-1} \frac{2}{3}$

28. A force of 10 lbs. acts on a mass of 1 slug. The acceleration is:
.....a. 10 ft./sec.^{2}
.....b. 1 ft./sec.^{2}
.....c. 32.2 ft./sec.^{2}
.....d. $\frac{1}{32.2}$ ft./sec.^{2}
.....e. $\frac{10}{32.2}$ ft./sec.^{2}

29. A force of one poundal acts on a mass giving it an acceleration of 1 ft./sec.^{2} The mass is:
.....a. 1 slug
.....b. g pounds
.....c. 1 pound
.....d. 1 gram
.....e. 1/g pounds

30. A body weighing 32.2 lbs. has a linear velocity of 10 ft./sec. The kinetic energy is:
.....a. 322 ft. lbs.
.....b. 50 ft. lbs.
.....c. 3220 ft. lbs.
.....d. 1610 ft. lbs.
.....e. 100 ft. lbs.

Perform the integration indicated in each of the following problems and write the result in the space provided:

31. $\int \frac{a+2bx}{ax+bx^2} dx =$

32. $\int x^{(3b-1)} dx =$

33. $\int \cos x \sin x \, dx =$

34. $\int \frac{dx}{(x+1)^2} =$

35. $\int e^{ax} dx =$

This correlation is about average for examinations and course grades as observed by the writer in previous work of this type. However, it may be rather difficult to visualize the meaning of these data and there may well be a tendency to note the cases of poor correlation too strongly. For example, the two students who received Bs in the course and scored but 10 in the placement examination might be cited as proof that the examination fails in the role of a selection device. However, one must keep in mind that human performance is not subject to such niceties of measurement as are physical quantities commonly dealt with in scientific and engineering work. If an instructor were able to select his students ahead of time and predict in what third of the class their performance would place them, he would feel that much had been accomplished. To present the data in a form which gives a picture of the results leading to an evaluation on such a basis, Fig. 2 has been pre-

	0 - 13	23	35
A-B	0	4	3
C-D	5	39	4
E-F	8	11	0

FIG. 2

pared. In this presentation the grades have been divided into three groups for both sets. It will be observed that fifty of the seventy-four students fall in the same category with reference to the grade on each test. For example,

thirty-nine received middle group grades in both examination and course. It should also be noted that no student's performance in the course was more than one level higher or lower than predicted by the examination. On this basis only nine students did better than expected and fifteen failed to perform up to the standard indicated by the placement examination. A part of the latter group of performances may well be due to the unrest caused by the war.

One individual performance is worthy of note, namely that of the student receiving a perfect score on the placement examination. This performance is probably not likely to be observed more often than once in a thousand cases, unless the average performance of this group is very low compared to that of all engineering students. It is a score approximately three times the standard deviation above the average.

The value of the individual questions was analyzed by making the following study. Each student's performance was recorded by noting the score on each question in tabular form. The tabulation was arranged with that quarter of the class which had the highest average score on the whole examination first, the second highest scoring quarter second and so on. The percentage of correct replies on each question was then calculated for each quarter and these percentages recorded in the chart shown in Fig. 3.

This chart presents in graphical manner the selectivity of each question quite forcibly. It is based on the assumption that the examination as a whole is a better means of evaluating a student's performance than is any single question. On this basis the block diagram for a good question would show a slope downward to the right. That is the first quarter of the

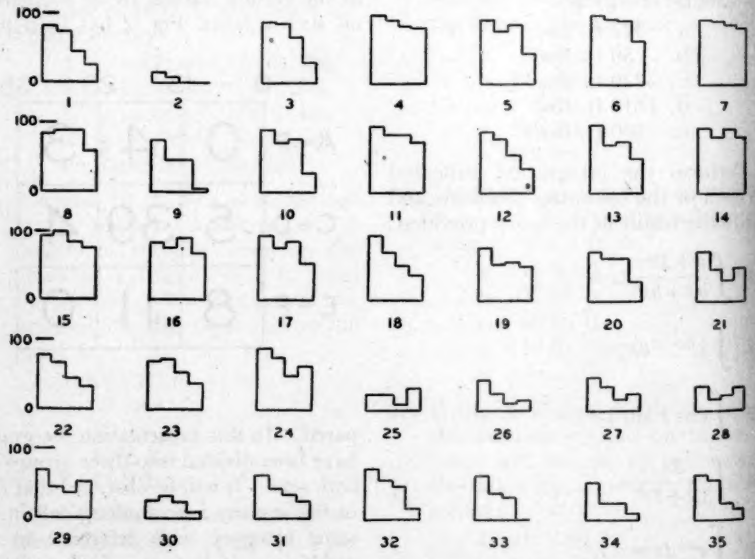

FIG. 3. Mechanics placement examination selectivity of questions

class selected on the total grade should perform better on a given question than the remainder of the students. Similarly, the second quarter performance should be superior to that of the other two groups but be inferior to the first. It will be noted that certain questions are notably highly selective while others have little, if any, value in differentiating between the students.

The relative case or difficulty of a question may also be judged from this type of diagram. If the area of the bar diagram is large the question is easy and if small the question is difficult. Again it is to be noted that the questions differ widely in this respect.

The following list points out the questions with outstanding selectivity or lack of it, and questions of exceptional ease or difficulty.

Excellent selectivity, 1, 3, 12, 18, 22, 32.

Good selectivity, 9, 13, 17, 23, 24, 31, 35.

Poor selectivity, 2, 7, 8, 11, 14, 15, 25, 28, 30.

Very difficult, 2, 25, 26, 27, 28, 30, 34.

Very easy, 4, 6, 7, 8, 14, 15, 16.

It is noted in studying the questions that those which show excellent selectivity in general require more than memory of simple facts. The best appear to combine the memory of a fact plus a use of this fact in solving a problem. The poorest questions are simple memory questions. The completion type question seems to be superior to the multiple choice with respect to selectivity.

An unusual feature of the examination is the fact that the average performance on the physics questions is notably inferior to that on mathematics. No apparent reason exists for this situation. It may be that this group of questions, simply by accident, was formulated as a more difficult exercise. However, it may be that these questions required more reasoning ability and less memory.

In summarizing this analysis, the following conclusions are presented:

1. The examination functions as a predictive device of some value, showing as it does average correlation with final course grades.

2. The value of the examination may be enhanced by revising the questions to obtain questions of higher selectivity.

3. The examination may be used to evaluate the student's preparation in mathematics and physics.

Proposals for Future Work.

Assuming that it is desirable to have available an examination which would serve as a means of predicting probable performance by students in mechanics, it is suggested that an examination of the type described herein might be used.

Wide use of such examinations might well lead to better understanding of the necessary preparation of students entering upon the study of mechanics.

Selection of students on the basis of such an examination and instruction in mechanics in sections of selected ability might well lead to improved instruction since each student could be trained up to the limit of his ability. Fewer failures and students more thoroughly trained in mechanics should result from such practice.

An Economic Consciousness

By FRANK SANFORD
Cincinnati Gas & Electric Co.

There are two phases of every engineering project in the utility business and in general manufacturing. They are of equal importance in our daily work and they are fundamentally interdependent.

We learn the voltage and structural design in our college courses, and we use the analysis based on engineering methods in all of our construction layout. But—and here we depart from our college training—we must make an estimate of cost for every design. Every extension, every installation and every operation started from an engineering department has an estimate of cost.

In the utility business we are selling units at a few cents each. We buy bolts and pounds of wire at a few cents each. Poles and transformers and a crew of workmen working a day all cost in dollar sums that do not seem large on the million dollar balance sheets. They are, however, the units that go into the work layouts from the smallest extension to the power plant addition.

Every job and every plan has an alternative. Every specification and every purchase has a cost comparison. Almost the first step a young engineer takes up on his earliest job, he has this idea of cost estimating and economic comparison as an important concept to add to his engineering calculations.

A college course—a few hours weekly for a year or so—teaches the fundamentals of economic analysis. It is important to know about depreciation theories, valuation methods and financial yields. To be well understood they should be related to the other courses in the college curriculum.

Perhaps we are keeping the mathematical calculations and the dollar calculations too much in their well-defined hours of our engineering courses. After a test on a transformer in the laboratory, would one additional problem in loss and annual cost be possible? In fact, do the students have any idea of the cost of the motor or rheostat or meter they use in the laboratory?

In our personal affairs we all learn from the first grade up what a pencil costs, what a necktie costs and how many cents we can earn at some task or job. As soon as we walk into the class-room we leave that sort of thinking behind. Then we walk into an engineering office on our first graduate job and find that every design is compared and criticized with at least as much cost consciousness as we personally have in buying a suit of clothes.

The acid test of every bright idea and of every expert design is—can we sell it; or, can we accomplish the result at less cost? Electrical engineering or machine drafting or chemical lab can all add to that economic idea. Some manufacturers' catalogs should be on the bookshelf of every professor and instructor alongside the latest handbooks. They contain some valuable descriptions with dollar signs in place of formulas.

Teaching Engineering Judgment in Machine Design Developing Abilities as Well as Teaching Techniques

By C. HIGBIE YOUNG
The Cooper Union

Let me start by saying that this is not an attempt at planning a super postwar program for teaching Machine Design. Rather it is a report on an investigation which started in 1939. It shows how we, at Cooper Union, have attempted to weave into our work some of the ideas we have received from this investigation and the direction in which we hope to develop in the future.

Our investigations convince me that there are some definite factors, such as initiative, judgment, and analysis, which enter into the teaching of machine design and which we have been relegating to a secondary role in order to accentuate the attainment of factual knowledge. Unless the student gets a feeling for these factors at the same time that he acquires his knowledge of formulas and the techniques of his subject, he must get them later. And until he does get them his value to his profession is negligible.

Let me outline the controlling features which influence any discussion of a planned teaching program. First, we must consider our objective, which is to prepare our students so that they are acceptable to industry not only from a technical standpoint but also along broader aspects. Second, we must keep in mind the material with which we are working; that is the students we are training and their limitations. And third, we are forced to remember that we are definitely committed to teach the subject of machine design.

It will serve our purpose to discuss briefly each of these in some detail. During the last few years in my conversations with the men who hire our graduates in the design field, I have been impressed with the unanimity of opinion expressed by them as to what they think we should teach. Almost invariably they say it is not what we teach that is so important, but rather how it is taught. I know as well as you do that they do not mean to be taken literally. However, if you draw them out you will find that they do have definite opinions as to what is required. They list among the prime requisites for a good designer the following: fundamental technical knowledge, initiative, judgment and the ability to analyse a problem and to weigh the answer.

It all boils down to the fact that they are not so much interested in the factual knowledge an applicant possesses, but rather in his ability to use it. This agrees with the classical definition of an education which states that an educated man is not measured by the

knowledge he possesses but by the knowledge he has assimilated and is capable of using. We all know and recognize that we can not teach all these abilities, but every student who comes into our classes has some latent abilities and it should be part of our duty to see that these are correctly developed and not dissipated nor allowed to lie dormant.

This brings us to our second consideration, the students themselves. Youth is an interesting period in life, but it is also a period of impatience. The younger generation has always been irked by the time spent in acquiring an education. Consequently, it is always looking for easy methods of learning. The students consider the memorizing of formulas and the mastering of the techniques of solving specific problems, the end rather than the means of acquiring an education. Their secondary school education, with its mass production methods, has accentuated this belief. The formulating of an approach to a problem or the discussion of the implications of the answer seems to them but a waste of time. Their attitude, fostered by all their previous experience, is to say: "Show us how to do the problem and then give us some data and we will grind out a numerical result and write a-n-s- with a period after it." This places a definite challenge before us. Should we, and can we, direct their attention to other phases of their education? Along what lines should such development take place and how much emphasis should it receive?

Thus we come right to our third consideration. Since we are teaching machine design, are we teaching it so that the student is getting the most out of the course? Or are we simply giving him some basic formulas and some standardized techniques? I believe most of us are largely doing the latter and consequently are not emphasizing the other factors that enter into the education of a good engineer. I can hear cries of dissension, but I shall attempt to show you shortly that the trend is in that direction. And in doing it that way we are failing in our duty both to our students and to industry. We can sum all this up by saying that our studies show:

First, that while industry is satisfied with the technical fundamentals the student is getting, it believes that he would be better prepared if more attention were paid to the other phases of education that make for a good designer.

Second, that the student by his very nature and previous experience can not be expected by himself to realize that the mere acquisition of factual knowledge is not in itself an education.

Third, that our present methods of teaching machine design are undoubtedly open to some criticism.

I have no panacea for correcting these faults, but I would like to offer some suggestions which I firmly believe will improve the product we are turning out.

We should revamp our presentation of the subject so that the student is forced to use logic in analysing the problem, judgment in selecting the relevant facts, initiative in sizing up and starting the problem and a critical attitude towards what he calls the answer. This can be done if we are careful to see that in preparing our syllabus, first things come first and that in solving subsequent problems the student is forced to use some of his previously attained knowledge. As the course develops more and more can be left to the judgment of the student

until, towards the end, he can be given only a broad general statement of the problem and then thrown entirely on his own. This means a careful consideration of the order and timing in the presentation of subject material.

At the expense of being accused of setting up a standardized syllabus, which God forbid, let me be more specific. Early in the course, the student should be acquainted with the general principles of mechanics of materials as they apply to machine design. This should include, besides stresses and strain, a review of impact and combined loading, and following this a discussion of repeated and concentrated stresses. The amount of time and the detail necessary would of course depend on the type of course in mechanics of materials the student has had, and where it has occurred in his curriculum in relation to the subject of machine design.

The next general group of topics would be materials and factors of safety. If the student has already gained a knowledge of physical metallurgy we can readily build on his familiarity with the properties of materials. If he has not had this course so early in his program it may be necessary to limit our discussion to the more common materials. Certainly he should know that the physical properties of materials influence their selection as machine members and how they affect the solution. He should also know where he can get information about these properties. A very complete discussion of the elements which enter into the selection of the proper factor of safety must also be included.

From then on the student in many cases can be required to select his working stresses in accordance with the principles he has already learned and may even be required to select the appropriate material to use. I realize that this is not always possible but at least some discussion of the controlling factors of the selection should be included and he should not be permitted blindly to use some prescribed allowable stress without knowing how it was obtained. As an instance of what I mean, I believe the student should know and recognize the features in the design which permit the use of a working stress around 50,000 p.s.i. in the calculation of steel springs, but would limit it to around 10,000 to 12,000 in the design of shafts. I deplore the fact that most books suggest the correct stresses in their development of the subject without explaining fully the reasons for their selection.

In the final stages of the course, especially in the work frequently called advanced machine design, the problem should be given in such broad terms that the student must select pertinent data as to material, etc., which he intends to use.

I insist that much more could be done in planning the presentation of the problem itself. I am convinced that if the question is properly worded it will create a feeling of actual design in the student and thus stimulate his interest. Too often the problem is so given that it is essentially only an exercise in arithmetic. How often do we see the problem stated: "Using the formula given on page X and assuming an allowable working stress —lbs. per square inch, design a shaft to transmit some horsepower at a given number of revolutions." Does this inspire any initiative or interest in the student? Let us try to reword it. "You are working on the design for the drive of a centrifugal pump and find you must use a short length of shaft flange-

coupled to the motor and the pump. In the interest of economy you should use cold rolled steel. Your preliminary calculations show that the shaft must run at 3,000 R.P.M. and that 5 horsepower will be required to pump against the given head. What diameter shaft would you specify?" Here the student's interest is aroused because there is a purpose to the problem and his initiative is required because he must select the proper allowable stress. He is also made to analyse the problem to select the correct method of solution.

Then the student should be compelled to weigh his answer. It should be stressed that his numerical result is only a guide to the real answer. This can best be done by insisting that the answer be a statement showing why the numerical result was or was not used exactly as determined. It may be simply a statement that it was rounded off to a commercial size or it may be a substantiation of the exact figures obtained. How often have you been appalled by a student saying that a member was unsafe because his calculations showed a stress of 10,050 lbs. per sq. in. when the allowable was assumed at 10,000? If the student is forced to justify his answer by a written statement he is more apt to be critical of what he gives as an answer. The minutia of the last decimal place will not loom as large as the importance of the correct number of significant figures. Let me illustrate what I mean by quoting one of our problems on brakes.

"The sketch shows a line diagram of the foot brake used on the drum of a mine hoisting engine. The cable is wound on a drum 30" in dia., keyed to the same shaft as the brake drum, and lifts a max. weight of 1,000 lbs. The speed in hoisting is very slow since the drum is geared to the motor. In lowering, however, the motor is disconnected and the weight is acted upon by gravity.

"Find the least force at the end of the lever arm necessary to hold the weight suspended in the raised position.

"If you were designing this mechanism which way would you specify to have it run when hoisting and why?"

The mathematical solution of this problem is of course very simple except that the students must correctly solve the trigonometry involved in finding the angle of wrap-around. The force required on the lever arm is a function of the direction of rotation and the answer for one direction of rotation is nearly five times the other. This places the emphasis on the second part of the question.

In all this, emphasis should be placed on the student being careful about his presentations. Carelessly scribbled problem solutions on odd scraps of paper should be taboo. However, I do not like the idea of handing the student some standard form and requiring that all work be entered on such sheets. Rather, I would again like to call on the student's originality. We do this at The Cooper Union by insisting that all students read the first two chapters of "Engineering Problems Manual" by Dana and Willmarth and then require all future problem work to be presented in a form which shows that they are following the ideas outlined. Each student may interpret his needs the way that suits him and the problem best, but we insist that all work must show the method of solution, all the calculations step by step, a statement of the dimensional units in each equation and clear, neat figures. In addition, adequate sketches

fully labeled must be at the head of each problem sheet.

I have been specific not to criticize the items given nor the work of other instructors, but rather to show clearly the direction our thinking should take. We at Cooper Union feel that what we are doing is worthwhile. The students do show a better interest in their work and we are inviting initiative and the use of judgment by the type of problem presentation and by leaving to their selection some of the pertinent material. At the same time we compel them to analyse the problem. And by insisting on a justification of the answer we make them aware of the implications of that answer. We do not make any claims that we have perfected this technique. We are doing the things outlined, but not by any means to the degree that we would like. It takes time and it must be a slow development, but we intend to continue along these lines. We might summarize what we are attempting at The Cooper Union by saying that we are:

1. Arranging the presentation of material so that once the student has mastered the factual material of any one phase he is compelled to use this material in the succeeding phases of his work. This may be either in the selection of data or the justification of the data as given.

2. Trying to create interest by wording our examples so that they are definitely engineering problems and not merely exercises in arithmetic.

3. Requiring the student to analyze the problems and use his initiative and judgment by the manner in which we give the data.

4. Making the student conscious of the implication of his answer by refusing to accept only the numerical results. No answer is complete without some statement as to the validity of the computed results.

5. By these means indicating to the students that their education does not consist of learning facts, but must be a continual integration of all they are learning so that they can apply the factual knowledge to the solution of real engineering problems.

Now let me take up some of the criticisms I feel most of you will want to make. First a great many will say that they are already doing this type of teaching. Yes: but still I believe much of it is only sporadic, and not at all a part of an integrated plan. Let us look at one type of question that occurs time and again in many textbooks—"Problem 78. Rework problem 77 using blank lbs. per sq. in. as the allowable stress and a load of dash lbs." Then problem 79 reads exactly like 78 except for the figures. Frequently all that the writer is saying to his readers is, "Here is the way to do this problem; now do several more just like it and I will say you know your stuff." Oh, No!! All he has done is to show a certain technique in problem solution, and then tested the student's ability to do arithmetic. A rewording of these questions along the lines suggested earlier in this paper, while a laborious task, would make them real engineering problems. It would also emphasize the differences in the problems so that the student would realize that while he is apparently repeating the previous problem the change in data affects the solution and entails different conclusions.

But one swallow does not make a summer, and so one example will not prove my point. Ever since I started teaching the subject I have been examining the way others have handled the material. In one case, I know that

after several class room periods on factors of safety, the test question was: "If a real factor of safety of 2 is considered desirable and the stress is completely reversed in each cycle and we may expect approximately 1,200,000,000 cycles what should be the factor of safety used to determine the working stress of a steel shaft of a gasoline engine? (Assume that there will be a considerable shock in applying the loads.)" As this was an open book exam, and the text had tables giving the factors to use, prescribed to narrow limits, all the student had to do was to look up the values and substitute. I claim that this was purely arithmetic. And, what was even worse, this was all that was ever done about using factors of safety. How do I know? Because the students said they were now through with factors of safety. They had had their instructor long enough to know what to expect.

Only a few years ago a number of teachers of machine design met to discuss the use of short answer forms of testing in this subject. Now I have no quarrel with this type of examination when it is used to test the right thing, and we do use it at Cooper. But most of the time we should be more concerned with student's comprehensive knowledge of the subject. The facts he can always look up, it is the approach to the problem and validity of the solution that is most important. To test the student's possession of these latter requires a more comprehensive type of question. Mind you, I am not suggesting we make handbook engineers, but we all know that no student can be expected to remember fifty percent of the multitude of facts he has learned in college so why not be realistic about it? Why not assume that he is going to look up factual matter and, therefore, put more of our efforts on teaching logical thinking, analytical methods of solution and critical selection of the results?

You will, of course, raise the question of the time required. Here I am definitely out on a limb. It does take longer to write the type of question I have suggested, and since the students are allowed so much more latitude in the selection of controlling factors, the correcting of papers will be more laborious. No longer will we be able to check the answers against a key. Each student's solution will have to be worked out independently. Frankly, at Cooper Union, we have largely called upon our enthusiasm for the extra time. Also since the student must spend more time in considering each question, the number of questions that can be asked on a given examination must be reduced. But our experience shows that what we have sacrificed in quantity, we have more than made up for in quality. Perhaps this will mean a curtailment of the coverage of the subject, but we do know that the student's early experience in industry will be rather elementary. He will be measured more by his ability to handle these elementary problems than on how much advanced technology his course contained. Therefore, it is important that we take the time to develop the student's abilities and to instill good work habits even if it does mean this curtailment. Once he is in industry and has proved himself acceptable in minor responsibilities, he will find the means and methods to advance his knowledge and prepare himself for larger fields.

In any discussion of this topic we must include the reaction of the students. At first they do not like it. This is natural when we remember what we said at the beginning concern-

ing the impatience of youth. But as the work develops some of them show a keen interest. This is evident by the discussions in class and the arguments they have with each other. These are the men who are keenly interested in the subject and who will make good designers. Others never do become quite so enthusiastic, but even if they do not have a flair for this particular subject, the experience will be of service in fields of greater interest to them.

I have purposely left out many details of the plan as we are operating it at The Cooper Union. I have not mentioned the fact that many of the problems we give incorporate the knowledge of such subjects as mechanics, kinematics, hydraulics, etc. Another detail omitted is how to grade the student's use of judgment. Can we hold an immature student accountable for judgment and how strictly can we penalize him for poor judgment? Or should the grading be in the form of extra credit for good judgment? As I have said before we are a long way from a perfect solution. I know that all of you can give us ideas, and I am hoping that you will criticize freely what I have said, so that I can take back to my colleagues some new plans to try.

Please do not assume that what I have said is a blanket condemnation of the present methods of teaching the subject. I was not satisfied with what we were doing at Cooper and I investigated how we could improve. Part of my investigation was to find out what others were doing along these lines. The fact that many of them were more or less in the same boat we were in, especially in the matter of integrating the material, led me to believe that this would be a timely subject for discussion.

DISCUSSION

By GEORGE F. NORDENHOLT

Editor, Product Engineering

In his paper, Professor Young has pointed out some real shortcomings in the courses in machine design as they have been given. Because I do not know in detail the courses as given in most of our engineering schools, I can not speak with the authority of Professor Young. My remarks are based largely on the modern machine design textbooks and I am assuming that these books reflect the manner in which machine design has been taught in our engineering colleges.

As one glances through the machine design textbooks now in use, it is obvious that little attention is given to the true relationship between stress and load. For example, most of the textbooks glibly state in words and formulas that unit stress in tension, for example, is equal to the total load divided by the cross-sectional area. One book, and possibly one or two in addition, approaches the true relationship by stating that the total tension load divided by the cross-sectional area equals the *average* unit stress. This erroneous presentation of the subject applies not only to tension stresses but to all other stresses and practically all of the equations and formulas given in machine design textbooks and in books on mechanics of materials.

Consider for a moment the magnitude of the error when we state that the unit tension stress is equal to the tensile load divided by the cross-sectional area. Surface roughness will cause points of stress concentration and hence failure at a lower stress. Prestressing at the surface caused by cold rolling or cold drawing changes the

stress pattern entirely and may result in increasing or decreasing the load at failure. Inclusions in the metal will have a significant effect. In the case of heat-treated material the mass effects in the heat-treating operation must be taken into consideration. Even in the case of metals not heat-treated, such as carbon steel or music wire, the specimens of smaller cross sections have increasingly larger tensile strengths.

All of the above refers to steadily applied loads. Even for this simplest solution, the answer obtained by using the equations as given in the textbooks will often be not even half right.

Because machine design has been presented in textbooks as an exact science, which it is not by any means, the student has been robbed of most of the opportunities for exercising his initiative and judgment. At least at the time that I taught the subject I must confess that there was little or no room for my students to "use their heads." The subject was presented almost entirely as "rule and rote."

The introduction to any textbooks on the mechanics of materials and on machine design should emphasize that these subjects are not an exact science. For example after introducing the formula relationship between unit stress, total load and cross-sectional area, the book should devote considerable space to explaining the limitations in the application of such formulas.

Most of the machine design textbooks give too little attention to the importance of strain or deflection calculations. Yet the fact is that possibly half of the actual machine design calculations made in industry relate to or involve the determination of the strain. Only by a careful analysis of the strains is it possible to determine the stress distribution.

Another criticism of the present text books on machine design is that th student gains the impression that usu ally stress considerations govern th material selected and the dimensio of the parts. Yet the fact is that i every actual instance the strength o the material is but one of many co siderations and frequently a minor co sideration. Cast iron is chosen for th frames of machine tools because of it ability to absorb vibrations. Alumi num is used for aircraft because of it high strength weight ratio. Stainle steel is used primarily for its corrosio resistance. Zinc die castings an aluminum die castings are rarel selected because of the strength of th material. In every instance, there ar economic factors to be considered.

Professor Young has summarized i five paragraphs how he is attempting t make his course in machine desig something more than the memoriza of rules and formulas. I am sure th most of us are in thorough agreeme with the five principles he has se forth. But unless there is a textboo available that presents the subject i its true light rather than as a rig science, I cannot understand how Pr fessor Young's five points can achieved.

I have only discussed the glari shortcomings of the present textboo on machine design. I can summari my criticism by the sweeping stat ment that none of the textbooks no in use give a true picture of the su ject. The worst feature of this is th machine design is presented as a "dr subject with lots of formulas and da that do not permit the application much logic in the solution of the pr lem. The drama of the subject hidden behind a curtain of abstracti empirical formulas and ideal equatio

that are not true to fact. No wonder few students find the subject interesting. Machine design problems are not solved by merely formulas. The process is really a game in which the designer uses factual knowledge, plus judgment, plus intelligent guessing. Students usually love guessing.

By ARTHUR L. TOWNSEND
Massachusetts Institute of Technology

The matter of "Teaching Judgment in Machine Design" has been brought up for discussion a number of times in the past. It may not have occurred in just those words, but it was included as the underlying objective in the ideal course in design. We only have to refer to the paper by Garland and Weibel presented at the University of California in 1940. The title of the paper is "The Objectives of Instruction in Machine Design." They list attitude, knowledge of factual information, and benefit of certain experiences. The purpose of this third heading was to help develop judgment.

Professor Young emphasizes in general this third item, the "development of judgment." I should even like to go much further and simply say that one of the important objectives in machine design is to develop judgment and common sense.

I have seldom found it in public print, but I have mentioned at earlier meetings of this group that machine design is not always given the importance to which it is entitled by administrative officers. Since it is not a completely highly mathematical course or does not involve advanced mathematics in all of its problems, there are those who thing it therefore should not be grouped in the high ranking courses in the curriculum. There are those who unfortunately think that machine design is more or less of a glorified drafting course with the application of a few empirical formulae. I hope in these few remarks to counteract those attitudes.

Of course there will be some exceptions, but by and large the first course in machine design in the average mechanical engineering curriculum occurs in the second semester of the junior year. The students will have had all of the general fundamental subjects—physics, chemistry, mathematics, drawing, mechanical processes, metallography, kinematics, some dynamics, heat engineering, and may have had an elementary course in electrical engineering. The machine design course, therefore, offers the first opportunity to bring together many or all of these preliminary subjects in the solution of a given problem. Every one of the preliminary or fundamental subjects can be well applied in the solution of a reasonable machine design problem. It is the first opportunity within reason where the student has a chance to exercise his own ideas as to materials processes, working stress, or factors of safety. It is his first opportunity to make assumptions as to sizes and then check them for adequacy. All of this is quite new to the average engineering student, and it takes time to develop self-confidence in these matters.

In our work in Cambridge we try to emphasize the judgment or common sense viewpoint of machine design. The fact that if a design is right it looks right; the fact that a man can usually find his own mistakes in the solution of a problem in machine design, provided he stops and thinks a little bit is stressed. To this end, for a number of years, we have reversed the usual process of giving examinations at

the end of a course. We have at the very first problem section in our junior and senior courses given an examination in machine design called common sense quizzes. These quizzes are used to impress upon the students that there are many problems related directly or indirectly to machine design for which they do not need a slide rule and which, as a rule, require straight common sense thinking.

These quizzes may have anywhere from five to eight problems. The problems include cross sections of equipment or pieces of equipment which possibly couldn't be assembled, and comments are asked for; castings which either couldn't be conveniently molded or which have obviously wrong construction. Comments are asked for on improvements in the design. Questions involving information from courses in mechanisms and materials and occasionally the so-called puzzle problem involving some algebra, etc.

The real benefit of these quizzes comes usually that night in the dormitories when the students get to arguing among themselves as to what the correct answers should be. The students are, once they have had their first inoculation, very enthusiastic about this test and agree that they learn a great deal.

I do not want to take up too much time, but I think that Professor Young ought to be complimented for emphasizing the importance of machine design and the fact that it is a place where all of us in the machine design group can do a lot of good in the education of our young engineers.

By FRED S. GRIFFEN

The University of Akron

As teachers of machine design, I am sure that we all agree that the objectives outlined in Professor Young's paper are very much to be desired. The imparting of judgment to the young engineer is, however, a very difficult task since the professional engineer has acquired judgment through years of experience. Nevertheless, there is no question, but what we could and should do more than we have in the past.

It would greatly help if all engineering teachers would continually emphasize the importance that judgment plays in all fields of engineering. Many beginning engineers and many people outside of the engineering profession have the idea that all engineering problems can be solved by a certain amount of mathematical calculation. A structural engineer might design a very fine steel bridge with all stresses and sizes accurately determined, when, if all of the facts were carefully considered, a reinforced concrete bridge would be the proper type for the particular job.

In machine design more emphasis should be placed on the conditions under which a machine is to be designed, manufactured, and used. If it is to be built, probably in large quantities, and sold in competition to other machines of a similar type, that is one situation. If, on the other hand, a firm designs, builds, and uses a machine for manufacturing process in its own plant, that is entirely a different situation. In the second case, it is likely that not many, and sometimes only one, will be built. Consequently the problems of designing for quantity production will not enter into the picture; the aspect of appearance is not so important, and sometimes the question of economy of manufacture does not play an important part, as long as the machine performs its functions properly.

Sometimes in this case the designer is instructed to use, as far as possible, material and parts already in stock.

A well chosen design problem, where the student makes a complete design of an assigned machine, can be made very valuable in increasing his initiative and judgment. In our course at Akron we assign such a problem in the second semester. We give the loads, speed, and general conditions under which the machine is to operate, but we do not specify stress values or the materials to be used. Neither do we give an exact method of procedure, but prefer to leave the student more or less in the dark at first. After he has decided upon a method of procedure, and has made some preliminary calculations and sketches, he submits them to his instructor for suggestions. He is advised to consult various textbooks, handbooks, and catalogs, and he often finds that authorities do not agree on stress values, material to be used, and other matters.

In this method of teaching, we realize that it consumes more time, and it is quite possible that the final design is not as good as if the instructor gave definite instructions from start to finish. But we feel that the student learns that machine design is not a routine process, and that much judgment and initiative is required before the job is finished. As Professor Young states, the students do not like this method so very well at first, but after some progress is made, they begin to show a keen interest and some of the arguments that ensue are interesting to the instructor.

Those of us who operate on the coöperative basis, feel that the experience the student gains in industry is very valuable. The fact that the coöp student meets a variety of situations, and works under mature and experienced men, helps to build up his judgment and to broaden his outlook in his particular field.

By E. S. AULT

Purdue University

How can I make much discussion about this paper when I agree with it so thoroughly? I have always looked unfavorably upon these substitution problems and have even engendered in my students some animosity by my ability to give problems that require them to think instead of merely substitute in a formula. I am so adverse to the use of formulas that I even dislike to use the term. I particularly dislike the giving of formula to the student to express natural relationships —work of friction in a bearing for instance. During our accelerated courses I find more than ever the great reluctance and shocking inability of students to apply basic principles to a problem which is different than any they have seen. What I have said so far has to do principally with analytical ability. The development of judgment is something else.

In teaching machine design, I try to teach the engineering approach to the solution of a problem. I insist upon a sketch and tabulation of the data and the items to be found. Most difficulty arises from not understanding the problem. I then insist that where assumptions be made that the values assumed be those that (*a*) have a limited range of value or of choice—such as the width of spur gear face in terms of pitch, and standard pitch values, (*b*) which if not assumed correctly, will have least effect upon the result—such as the velocity factor in the Lewis formula, (*c*) are consistent with com-

mon experience. By proper handling of method lack of experience may be minimized. A student undertaking a new subject is understandably reluctant to make assumptions. He is always surprised how common sense will guide him. In fixing upon some unimportant dimension which is not readily calculated he will at first refuse to hazard an opinion. Asking him "Is it as small as—?", "Is it as large as—?" generally leads him to make a reasonable estimate. The student must be guided and prodded, however, for it is much easier for the student to ask for and the instructor to give a definite answer. After all, does not the student save time and the instructor show how much he knows by this prcoess?

By R. R. SLAYMAKER

The Case School of Applied Science

The 1941 Pontiac six is for all practical purposes the same engine as the original six built in 1936 except for speed. The 1941 engine runs much faster. Having given a connecting rod bearing which did an admirable job in 1936, what should the 1941 bearing be? Will the old 1936 design be satisfactory and if not, why? If changes have to be made, what should they be? Here is a situation in which the designer has plenty of opportunity to use his judgment, but his ability to solve an equation for a numerical answer will not help him a bit. His knowledge of the relation between the variables will, however, help him to decide whether a given change in design will help or hinder the situation. In this instance, for example, the results are purely relative (since it is impossible to depend on a numerical answer for such things as maximum oil film pressure or minimum film thickness) and we are interested in providing a bearing which will operate satisfactorily at a certain percent increase in speed and a certain percent increase in unit load. The exact or even the approximate values of any of the other variables usually considered important are of no consequence whatever. This and other situations like it lead to what we at Case School call the "better or worse off" type of question.

To my mind, solving for a numerical answer of any kind, be it stress, diameter, deflection, length, time, etc., from a given set of data involving horsepower, speed, temperature, etc., is so much overemphasized that the relation between the variables is often obscured. In other words, the student is so busy passing his courses that he has not the opportunity to get an education. More often than not, a designer is confronted with the necessity of making changes in an already existing machine and his ability to grasp the relation between the variables involved may save him considerable time. In this Pontiac job, for example, a few questions can be answered without putting pencil to paper.

(1) All other variables kept constant, should a given increase in speed be accompanied by a decrease or an increase in unit load if the bearings are to perform as in 1936?

(2) But if the engine is to have its speed increased, what is bound to happen to the unit load?

(3) Will the oil film thickness be decreased or increased by increasing the radial clearance?

As another illustration, suppose that an existing belt drive transmits a certain horsepower at a given speed. Will loosening the belt increase or decrease the tight side tension? Does

slip and creep increase or decrease with an increase in tension ratio and how are these variables related to belt life?

Suppose also that it is desired to increase the critical speed of a given shaft carrying a given load. What can be altered and how will the changes affect the critical speed?

In the case of a given spur gear drive, what must result if involute interference is to be avoided by cutting the same number of teeth on oversize blanks?

One last obvious illustration. Suppose that a part in a given machine is subjected to flexure and that it is desirable to increase its strength. If the part were rectangular, would it be more desirable to increase its depth or its breadth?

No one could quarrel with Professor Young's objectives for all of us are trying to do the same thing. We all agree that the student should be given an opportunity to use and develop his judgment but we are likely to differ in the methods we employ. I doubt if any one formula will be found which will suit every design instructor. We must all be guided by our own experiences.

By L. M. SAHAG
Alabama Polytechnic Institute

There are two factors which should not be overlooked. One of these is the actual industrial experience of a machine design teacher. One who has never been in a drafting room, or had nothing to do with actual designing—his experience and knowledge obtained from the texts—is unable to see why a particular design is poor from a practical standpoint although it may be correct according to known formulas. This means that mere mathematical calculations cannot be considered accurate and unalterable.

We have perhaps seen that according to some known formulas the size of a bolt may seem correct, but in comparison with the parts to be tightened or compared with the whole object may be found out of proportion. I have seen many practical designers or engineers who are able to give exact size dimensions of objects to be designed, when ordinary equations fail to do so.

The second important factor is that mere calculations together with small sketches of parts submitted are not sufficient or complete for a certain design. We know that even in a simple machine there are parts for which we have no definite formulas, while their actual form and size will play an important part in the completion of the design. In this case, a *preliminary assembly* drawing in pencil (or ink) must be a required work showing how the parts as calculated fit together and just what changes must be applied to improve the design. If we remember that our theoretical calculations based upon equations or formulas given in mechanics, strength of materials, etc., assume that the materials are homogeneous whereas this is not the case, hence our calculations must be based upon experience and judgment. If such a routine is exercised, I am convinced that our machine design courses will become not only interesting, but the results will be close to those that can be obtained in actual industrial practice.

By F. S. ROGERS
Cornell University

This paper brings to our attention several suggestions about which we should be thinking. Below are a few brief observations related to the topic.

1. Keep design discussion and problems on a basis of design; that is to determine the proportions of something to be made and not on the basis of merely checking something that some other person has already designed.

2. In a design problem encourage the student to make his own design, work with him on that design, but before the problem is left discuss the results, both favorably and unfavorably, and perhaps have him erase and make certain corrections. I feel that the student should make his own design, that it should be finished, and that it should be corrected so that it is not a bad design.

3. Too much emphasis is often placed on the saving of a student's time. Usually experience is the item the student has the least of and he should not be taught short-cut methods of computing but rather basic principles and the reasoning back of each progressive step.

By WALTER L. ROBERTS, JR.
Howard University

Any effective discussion concerning machine design must be prefaced by some basic philosophy of engineering education. For in machine design the student is expected to draw upon much of the knowledge he has assimilated in his other courses and to apply discriminately such knowledge to the particular problem at hand. The subject of machine design, then, might be considered a link between the school and what is to follow.

Too many sins are committed innocently by institutions and their officers of instruction under the banner of "preparing students who shall be acceptable to industry." If the climax of an engineering student's college life is to be determined by such standards, then the cynical observer may rightfully ask why the engineering school does not pack up its trappings and trek off to the factory and thereby gain for itself many obvious advantages. Since the engineering school is still on the campus it must defend its very delicate position of being allied with and yet detached from industry. Now what is "acceptable to industry," when impartially investigated and carefully considered, too often does not offer sufficient challenge to an institution nor is it made of such good stuff as to be the unquestionable obligation of the institution to the student. The responsibility of the engineering school should be to arrange a program to educate the student for life, *i.e.*, the responsibility is to the student first, and not industry. It logically follows that the range in which the school's ideological influence can be effective is indeterminate. It would seem, therefore, that the target for the school is an indefinite distance beyond and a little to the left of the center of industry.

What has been written above is of special significance to the subject matter of this discussion. For in the teaching of machine design, the alert instructor has a complex responsibility. Into his custody comes the raw material which he must prepare for future processing. His task is to excite and entertain certain capabilities in each student, who, until this new acquaintance with machine design, has generally been the innocent victim of scholastic discipline. He must carefully weave his way through the mine fields of arithmetic, empirical equations, and some outmoded rule of thumb methods in order to capture those very fundamentals of all engineering design: analysis, initiative, balance, and atti-

tude. To guide him, there is no official map or "unimpeachable sources of information." If he is sincere he must devise his own techniques in order to complete his mission.

To discuss these all important intangibles and some of the techniques with which to exploit them would require a paper of great length. The introduction, however, for such a project may be found in the closing sentences of this discussion.

Perhaps the most necessary and also the most difficult phase of teaching machine design is the process of cultivating the student's ability to see the sum of the parts—the whole, the primary function of the machine. A machine is no longer considered acceptable because its parts are empirically correct. New demands are being pressed. It must "mass produce" readily; therefore its individual pieces must be of economical design: its design must allow for speedy assembly and breakdown; therefore its groups of mechanisms must be of logical sequence: its appearance must be clean and convincing lest it be necessary to call in an industrial designer to package it. A planned series of sketch problems executed on cross section paper with some necessary computations will stimulate the student's desire to interpret and translate the whole as a logical sequence of the parts. Such sketches may be three dimensional after the fashion of a new trend which is being developed in aeronautical design.

Other teaching techniques practiced in relation to the work in the mechanical laboratory and the strength of materials classes will complement this attack to develop judgment and analysis.

Now is the time for the instructor to take account of his method of teaching machine design and to ask himself if the techniques he is using may be superseded by others which will encourage these necessary engineering fundamentals: judgment, analysis, balance, and attitude. Now is the time for the engineering school to examine its prescribed course of study and to determine in what way it may substantiate any attempt to nourish these capabilities. The problem is now clearly stated—let us strive for a successful design.

By ERNEST K. GATCOMBE

Cornell University

One might ask—Can we really teach "Engineering Judgment" to anyone? Rather do we not teach students those basic underlying principles of engineering, and thus impart to the individual a knowledge which suffices to permit the student to form his own opinion or to form his own judgment concerning the solution of problems? We may judge one another by certain specific characteristics, but I am skeptical about our ability to teach judgment.

If, however, we agree with the author that "Engineering Judgment" may be taught, then we are committed to teach it properly. Personally, I feel that initiative, judgment, and ability to analyze are as important as the attainment of factual knowledge. An engineering graduate should be taught the proper material and taught that material in the proper fashion. It should not be necessary for the student to flounder in attempting to solve a problem. He should *know* proper approach. It is conceivable that students well trained in mathematics might learn the proper approach to the solution of problems more easily than those who have poor mathematical training. It

might be well for us to give the student a little more theory while he is in college. This should help him in his ability to analyze.

If he does not get an academic background in machine design while he is in college, he is not likely to obtain it at all. With our design problems becoming as complicated as they are, especially in the field of aeronautics, we teachers in machine design must do less and less of the teaching of empirical work and really impart to the student some knowledge upon which he may rely.

By RAY M. MATSON

Southern Methodist University

We have not made any extensive investigation on the matter of developing abilities as well as teaching techniques in machine design, but have been following the general plan and objectives which are presented in the paper. The past experience of the writer in industry and teaching has shown definitely that the successful machine designer should have:

(1) A natural flare for design.

(2) A basic foundation of physics, chemistry, mathematics, shop, and other allied subjects.

(3) An ability to sense short cuts, by-pass obtuse theory when advisable, patience to develop by theory when necessary.

(4) An inquisitive frame of mind: desire to try out an idea that "cannot be done," common sense enough to drop it if it "CANNOT BE DONE."

(5) An appreciation of shop limitations and economic considerations.

The instructor must realize: (1) That he is teaching the student; (2) That he is teaching machine design. This merely means that he must start his teaching upon the student's level and lead them on to advanced work. He must be able to recognize the native abilities of the individual students, and encourage them to think for themselves. The normal peace time use of the Cooperative Plan at this school, Southern Methodist University, assists materially in screening the students so that we have a large percentage of men with many of the above noted characteristics. A small student body makes it possible for the instructor to know and analyze his students and direct their energy so that these characteristics may be more completely developed.

In order to attain these objectives we have four courses in design in the junior and senior years:

(1) Elementary machine design—in fundamentals.

(2) Theory of machines—in analytical and graphical methods.

(3) Mechanical design—in elementary sub-assemblies.

(4) Mechanical design—in complete project.

In the first course, problem book statements are used with as complete as possible reference to practical applications and modifications. In the third and fourth courses the student is encouraged to think for himself and to devise new and unusual combinations. Some time may be consumed in false starts, but the results impress the student with a sense of knowing why certain design work and certain other variations do not.

By W. W. FINEREN

The University of Florida

Professor Young should be thanked for bringing this timely discussion to the attention of teachers of machine design. For several years the writer has thought along these lines, and, some-

times, when the students seemed to resent his interpretations, he felt that he was alone in his efforts to teach ideas and not mere abstract quantities. Not only do students seek the easier way out in solving problems merely to get the answer, but sometimes we fear that instructors seem careless or indifferent in such matters.

In our machine design teaching we have been giving practical problems of such nature that one part follows another in sequence. Thus, a series of four problems, illustrating the natural steps in design, will all hinge on the first part. The second part will depend upon what value has been chosen for the first part, and, if the answer to the first part is in error, all parts of the problem (four problems in effect) are wrong. Students who may be able to work the second or third part but who cannot work the first part will often rebel when marked down for an erroneous design, but we have consistently insisted that the design must be correct as a whole for credit. We explain to the students that knowledge of how to design a gear will be of little value in the machine if the shaft holding the gear is only half strong enough. Correspondence from graduates, five and ten years out of college, all testify to their later appreciation of this attitude on this instructor's part.

We have consistently impressed upon the students the fact that *"the bridge fell down"* because of the careless mistake in a decimal point in the drafting room. Engineers must be *responsible* for their mistakes and carelessness must not be tolerated. Several years ago one of the brightest students we have ever taught made a design of a cam to do a certain specified work. It was a beautiful drawing. Every theory connected with the design was correct. But the cam, as designed, dropped the follower when it should have raised the follower. The student, who was marked zero for the design, complained. No doubt but that some of my fellow instructors might not agree with me. The student wanted credit for the beautiful work. He wanted credit for his knowledge of the laws of cams. But when I explained that if he had made the cam for a client in practice, the cam would have been refused and not paid for, and that he would have lost all of his time and material, he was convinced that he should have given more thought to the *requirements* before making the design.

Not all the blame, by any means, falls upon the student. We have not always properly interpreted the laws by which machines are designed. In one case, several years ago, I asked the class on examination to *"explain* the section modulus." Every man in the class answered the question by saying the section modulus was I/c. We marked the answer zero on every paper, and, as expected, had a war on our hands the next time the class met. That's what the boys had been taught and that's all they knew, and they all knew that their instructor (the present instructor) was wrong. And they did not like it a bit. "Smith," said we, "what is a dollar?" "One hundred cents," said Smith. "Wrong." "Isn't there a man in the class who can tell me what a dollar is?" Finally one boy said, "a dollar is a medium of exchange." "Correct." "Now, Jones, what is the VALUE of a dollar?" "One hundred cents," said Jones. "Now, Smith, can you tell me what is section modulus?" "Oh, professor," said Smith, "I know what you mean now but I cannot tell you." "All right, Smith,

section modulus is a relative value obtained for an area of section by placing the bulk of the area in the section outward or inward with respect to the neutral axis, with the idea in mind that the further the material is outward from the neutral axis the greater is its resistance to bending on that axis. Thus, a long, thin, section has a greater modulus and greater resistance against bending than a short, fat, section." "Now, Smith, what is its VALUE?" "Its value is I/c," said Smith.

In this connection we gave the students a curved beam to design in the form of an I-beam section which was limited to 1 to 2 ratio in outer dimensions, and we suggested a 6" by 12" I-beam to begin with. Our answer was a beam 19.38" high, 9.69" wide, with flanges and web of 1.615". Some of the boys refused our suggestion, for the purpose of being original, and chose a tentative I-beam of 5" by 10" and their result in the design was a beam 17.2" high, 8.6" wide, with web 1.72" and flanges 2.58" thick. The students' beam held the load on the machine equally well as our beam, but when we analyzed the results with them and showed how they had wasted material and money in ignoring the section modulus idea advantageously placing their material, they acknowledged that there was more to machine design than merely learning how to do simple problems like they used to do in arithmetic in their earlier days.

We stated that students were not all to blame for their lack of desire in securing anything but abstract results. Very much to the astonishment of this instructor's engineering friends we have been condemning the too widespread use of the slide rule in preparatory schools. I state this at the risk of being misunderstood after 42 years as a professional engineer and teacher. Just as a man who has ridden his automobile constantly for twenty years cannot walk a mile, so these students coming to me are not able to "figure" without their "slip stick." A very prominent educator told this instructor only a week ago that in the lower grades his nine-year-old son was taught to print all of his work and was not allowed to write any of his work. Our rising generation will be printers who cannot write a letter and "slipstickers" who cannot add and subtract.

I gave a recent class in machine design a design of a joint held together with a square pin, $(a) \times (a)$ in dimensions, and asked for the size of the pin. Forty per cent of the class gave the answer in terms of (a) squared = 0.386 square inch, and could not give the value of the square dimension (a) because they had no slide rule. I marked every man zero, and asked them what the machinist would do to machine a proper pin, as certainly a college man ought to know more than a machinist.

While some teachers tell this instructor that he is overanxious and unduly severe, and that the boys will finally whip into shape as they get older, this instructor is frankly worried about present tendencies in teaching machine design, probably with more emphasis on the teaching of subjects *leading to* machine design. We therefore appreciate very highly the efforts of Professor Young in stirring up some comment on the subject.

By W. G. McINTOSH
University of Toronto

The teaching of machine design has always presented many problems; the increasing tempo of development dur-

ing the past few years has not reduced the difficulty, and Professor Young is to be commended for the broad viewpoint in the manner of his presentation.

Some of the difficulties involved are: lack of interest and practical knowledge on the part of the student, lack of time for proper presentation, inability of the student to apply the basic fundamentals, and inability of the student to do arithmetical calculations, accurately and with reasonable speed; combined with a very broad field and a very great lack of definiteness or uniformity of procedure.

The author has stressed the need for careful planning and presentation of problems to overcome the lack of interest. Our methods, and results, appear to be somewhat similar to those at Cooper Union. Our experience generally has been that a problem which has been carefully planned and presented gives more satisfactory results the first time it is used than when repeated in succeeding sessions. This is apparently due to a greater interest, enthusiasm, and better preparation on the part of the staff following the period of development of the problem.

It is true, of course, that many students are interested in internal combustion engines, aircraft, plastics, etc., but we have not had much success in introducing design problems on such equipment, due to requirements of special knowledge obtainable only by research or practice, or the fact that the problems would be too complicated for any reasonable solution in the time allotted. Further, the value of such problems in teaching the applications of basic principles and in developing fundamental technical knowledge, initiative, judgment and ability to analyze a problem and weigh the answer, is very doubtful.

The lack of practical experience on the part of students makes the presentation of problems difficult and, in many cases, reduces the judgment of the student in his analysis of a problem and his answer to something approaching a guessing game. I think it is true that, if sufficient time were available, the student could be required to look up published material in journals and catalogues so that he would be in a position to at least make a comparison such as he no doubt would do in most cases in industry.

It has been our experience that the majority of students require considerable practice in the work on basic fundamentals and in both the accuracy and speed in arithmetical calculations. It is a question whether some form of a quantity of direct questions would be more desirable than trying to combine this work with machine design problems. If reasonable accuracy could be attained, much of the detailed work of the arithmetic of the problems could be eliminated by the instructor and more time and thought given to the form and procedure, etc., in the students' work.

It seems to me that accuracy, neatness, and form of solution should be given particular stress, although I agree with the author that a student should be encouraged to develop a method of his own in preference to a hard and fast prescribed form.

The question of quantity versus quality is answered, in most cases, by a compromise. If a proper interest could be developed, there is no doubt but that quality would be the correct answer. Unfortunately, that is not usually possible with even a majority of a group of students. The attainment of quality is difficult, and one

frequently feels that by quantity of work, students at least gain something by doing, and perhaps an interest may be developed in a portion of the work.

By D. D. PANABAKER
University of Toronto

Professor Young is to be commended for discussing a problem of primary importance to anyone teaching machine design. The method he describes is certainly a step in the right direction, but our experience would support his suggestion that the whole solution is yet to be found.

We have been using problems of reasonably wide scope, presented, as far as possible, to duplicate typical assignments in practice. Simple units or particular parts of a large machine are used for our problems, with less and less data given as the student progresses. Early work is often presented as a checking problem rather than as one of design. However, this approach does not necessarily assure that judgment, initiation and analytical ability will be developed.

It would seem that the capable and interested students do tend to develop their abilities, but many are quite content to follow the lead of others or become hopelessly involved and flounder discouragingly. There seems to be a very narrow line between conditions of spoon feeding on one hand, and those which cause useless floundering on the other, although the ratio of students to staff members is a very important factor. Our present procedure is to supply analysis sheets indicating the basic steps in the design without introducing details. The problems are also discussed with the group as a whole, to provide perspective and background. We feel that a limited number of problems, that necessitate the selection of elements of a design from commercial catalogues, tend to develop a cost consciousness and practical judgment.

We are certainly not entirely satisfied with the past procedure and plan to use two new approaches next session. In the first place, we plan to allow the student one or two periods for preliminary analysis on each problem, with very little guidance. After this we will discuss the basic principles of the design with the whole group, endeavoring to have the group supply the ideas which a staff member, acting as discussion leader, can organize. This will give the capable men an opportunity for original analysis, but will guide the others before they lose too much time. Moreover, it will give this latter group some idea of how a problem should be approached.

We also plan to arrange our work so that the more successful students will have five or six weeks at the end of the season for the complete design of a simple product. In some cases, two students may collaborate on the same design. The problem will be given in the broadest terms and the students will be given every latitude. The problem will be assigned in midsession in order that data from various sources can be obtained and the student will be encouraged to visit representative manufacturers where this can be arranged.

Although the success of this approach is yet to be proved, we feel it should increase student interest and also develop the qualities Professor Young has mentioned. We would be pleased to hear whether others have tried such a procedure, and with what success.

By I. W. SMITH
University of Toronto

The objective of training students to exercise judgment in machine design is a very laudable one. As Professor Young points out, this is difficult to achieve because (*a*) more time is required to do a given problem, (*b*) the students prefer to be guided rather than be left on their own, (*c*) evaluation of the finished problem is more difficult.

We have had some experience with most of the suggestions given; none of the problems we give are taken from a textbook; even the simplest torque problem is worded so that it sounds like an important engineering calculation. If the student cannot do an entire problem, we try to make him feel as though he were part of an engineering team—someone else has prepared the groundwork for him, and will carry it on if he cannot finish.

We expect students to select factors of safety, materials, sizes, and to produce original designs. In some cases, each student works with different data, but even when a class starts with the same values, the solutions rapidly diverge and cannot be checked against a "standard solution." More time is consumed in checking such work, but it gives greater satisfaction to both staff and students.

I do not think that a student should be expected to exercise judgment at the outset. It is much better to develop confidence at first by having him check actual parts for strength, following a fairly general procedure. The poorer students usually take longer to acquire this confidence and sometimes they never do. I think our experience has shown that it is best to give complete guidance at the beginning of the course and then gradually withdraw support—by supplying less data, by outlining less of the procedure, and by giving fewer direct answers to questions—until the students can carry the solution through by themselves.

The student's judgment is liable to mislead him into a wrong solution. This creates a problem for the staff because the student when he finds his classmates finished while he has yet no satisfactory answer, becomes very discouraged and resorts to the plea "You don't get anywhere by working by yourself—so-and-so gets better marks by copying all the time." It requires a real selling job to convince this student that his wrong answer is worth more to him than so-and-so's right answer. It is also necessary that the staff show considerable restraint when deciding what is a wrong answer. If the student's judgment is to be developed, he must be made to feel that his results are worth while—and this cannot be done if he is made to feel that his judgment was wrong—*even though it did disagree with that of the instructor*. Of course this is not to say that the student is always right. When a student comes up with what I consider to be poor design I point out where it differs from standard practice and I suggest troubles that it *may* give rise to, but I do not insist that he discard it. This policy has proved to be a correct one in a number of specific cases.

Professor Young has put his finger on a real problem in connection with having the student comment on his numerical answer. Occasionally we have the odd student who rejects a design where the stress is 10,050 instead of 10,000 p.s.i., but this is not a usual case nor is it difficult to correct. We have more trouble with the man

who is working to a permissible of 10,000 p.s.i. and comments "O.K." when the actual stress is only 2,000 p.s.i. He would rather accept an obvious over-design than re-work the problem. Students in general do not like a trial and error procedure—they prefer a direct formula-to-answer method, and for this reason the teaching of initiative, judgment, and analysis is an uphill road.

By DANIEL VAUGHN WATERS
Western Electric Company

Machine designing really is the practice of, first, visualizing and roughly planning a mechanism which will do what is desired; and, second, selecting proper materials, and evolving detail constructions and proportions, so that the finished structure will perform as intended.

Most young engineers hired nowadays in the design field appear to be able to solve force and energy problems set up for them, have a fair knowledge of the simpler phases of kinematics and mechanics of materials and possess some idea of the characteristics of the materials of construction most commonly used. Very few are able to do any great amount of the visualizing and planning before mentioned. This is not surprising, as such ability usually results from practice. Also, many young design engineers do not seem to have been trained in the independent thinking mentioned by Professor Young which is necessary before proper selections of materials, safety factors, stresses, etc., can be made, nor do they seem to be able to consider the problems associated with the operation of a mechanism and arange them in forms which can be attacked and solved by the simplest methods and in a reasonable time. However, it is fortunate that, in most engineering departments, the young employee usually does his work under the guidance of experienced men and is able to learn how to analyze his problems and set up proper solutions.

Undoubtedly, engineering schools can, by use of proper teaching techniques, do much toward inculcating the ability and habit of original and independent thought. Above all, the school should endeavor to ground the student so thoroughly in what I call "first principles" or physical fundamentals that he will not be altogether dependent upon textbook methods, formulae and constants, except as he intelligently uses them to save time and needless memory effort.

Professor Young has made a valuable contribution to teaching literature.

By CARROLL D. BILLMYER
Rhode Island State College

The writer agrees most wholeheartedly with the author as regards the general aim and method of presentation. He knows that the time allowed for machine design in the usual undergraduate course makes it difficult to give as thorough a foundation as industry desires.

These same time limitations prevent the proper coverage of all types of stresses in the usual course in mechanics of materials. In addition to problems involving stress concentrations and fatigue, the writer gives problems involving practical applications of stresses statically indeterminate, emphasizing not only the rational but also the experimental means for their determination. As he has no apparatus, he makes available to his students reprints of current periodical literature and the *Proceedings of the Society for Experimental Stress Analysis.*

His own commercial experience indicates that the author is on solid ground in his demand for neatly arranged reports, accompanied by clear sketches. While time limitations prevent the actual calculation of alternate designs involving different materials or methods of fabrication, brief reference to such alternate designs with economic implications should be encouraged.

We teachers of machine design are confronted with an expanding field and insufficient time. It requires all our ingenuity to provide graduates with a better knowledge of theory and the growing applications of this theory. We must fight constantly to preserve a proper balance between theory and practice, with industry's role kept constantly in mind.

By W. R. HALLIDAY

Stevens Institute of Technology

I quite agree that it is important as progress is made that the student should realize that, in addition to finding applications for material in prerequisite courses, his previous steps in machine design have prepared him to handle the more comprehensive problems. Sometimes simple early problems can be picked up again and extended to include topics coming later. The student will be quick to recognize the helpfulness and necessity of the individual stepping stones in the total progress made. The more stepping stones used the better. This gives apparent future value to the current work and, along with suitable problem statements, is bound to stimulate interest.

We find that "open book" problem work places emphasis upon the "ability to use" pertinent information. Incidentally we do not hesitate occasionally to supply a superabundance of data so that the student must select the items which are useful in applying his scheme for solution. We try to emphasize the importance of a clearly thought out scheme.

Because of the general value of an orderly presentation of engineering work such training as is suggested may prove to be one of the most valuable bits of training received. The worthwhileness of developing also the ability to analyse and interpret results can hardly be overestimated.

A vital part of any such program is the training and holding of a staff with a full comprehension of what is being planned.

By J. GEORGE H. THOMPSON

A. & M. College of Texas

While Professor Young and I do not see eye to eye on one or two little matters, I feel that this paper is a real contribution and that it offers food for thought that we all could well consider.

Machine design is not done on paper. The designer is not so concerned with the plans on the drawing board as with the actual machine represented by those plans. The distinction is significant. The calculation of a stress, for example, is for the purpose of making a machine. Somewhere along the line the machine has to appear, and the reality of this finished product is ever present, even from the first moment the designer starts his work. Furthermore, no one contribution to this final product may be considered as being complete until it has been balanced by all of the other considerations. Good design is possible only by considering the designer and the organization of as many points of view as the calibre of his company will permit.

In weighing his evidence, the designer is usually faced with a problem

1. Part Name	JOB ANALYSIS SHEET
2. Number Required	STUDENT
3. Material	JOB # DATE
4. Raw Stock Bar ☐ Sheet ☐ Forging ☐ Casting ☐	
5. Special Instructions	
6. Can you see how the production of the part can be improved by slight changes in shape, size or material?	

7.	Description of Operation	Machine or Bench	Remarks

of choosing between divergent ideas. For instance, simplicity and unitization are both well known and well recognized principles of good design. Yet we all know that the one is usually enjoyed only at the expense of the other.

In helping the student to evaluate his answer and to develop good judgment in his design, the use of a JOB ANALYSIS SHEET has proved worthwhile. This form requires the student to visualize how his part is to be made. When he sets down each operation, just as it would appear on an OPERATIONS SHEET, he is learning to concern himself with some of the problems met in the shop.

By JOHN A. PRIOR
University of Pennsylvania

I agree so completely with the ideas that any discussion I could give would be only a rehash of them. Particularly I like the emphasis on the design of problems, which certainly is the backbone of design courses. Students can hardly be expected to get more out of a problem than the teacher has put into it.

My only suggestion is that in the oral presentation a little less emphasis is put on acceptability of graduates as beginning designers and more on the contribution of design study to the education of *all* engineers, most of whom will not be designers. Every one of the abilities emphasized is just as valuable to research men, managers, and sales engineers as to designers. Unless we emphasize this fact, design is likely to be regarded as a specialty, and crowded out of undergraduate curricula. Furthermore, most of the practices condemned are the result of the

"training" viewpoint as contrasted with the "educational" viewpoint.

CLOSURE OF DISCUSSION

By C. HIGBIE YOUNG

The author wishes to express his deep appreciation of the many letters of comment, and the keen interest shown by the members in this paper. The 19 formal discussions received were quite varied in their coverage of the topic, so much so that an individual comment on each discussion would be time consuming.

There are, however, a few points which have been brought out by the discussion on which the author feels he should comment. A number of instructors have written in lamenting the lack of emphasis on drawing room work. In preparing the paper, the writer had not divorced the classroom work and the drawing room work. He feels that the very name, Machine Design, means that drafting work must be part of a completely integrated method of instructing. He knows that in some schools actual machine design drawing, as such, is not given. He cannot agree with this, as he believes it is a shortsighted policy. The student does get the concept of designing individual parts, but it is only when he makes a scale drawing that he appreciates how hard it is to fit parts together adequately. It is here that he experiences the use of judgment in arriving at an acceptable compromise. Also, in the drawing room he realizes that he is designing something that is to be made and not performing a check on some other designer's work. Professor Rogers, of Cornell University, stressed this point, and the author agrees with him. First, because the student feels that he is originating something. Second, it gives him confidence to try the unknown. Here, we, as instructors, must be very broad-minded. We must permit the student to make his own design rather than point him toward a stereotyped solution. On the completion of the work, our criticism must be offered in a very circumspect manner, and we should be equally careful to make favorable comments as well as to criticize the unfavorable aspects of his design. In this way, we encourage him in individual thinking but show him that great care is necessary in such work. This was pointed out by Professor Smith of Toronto.

Mr. Nordenholt, Editor of *Product Engineering*, brings up the very ticklish question of adequate textbooks. The author has long felt that the textbooks available are not all that could be desired, but he is well aware of the fact that probably no one textbook could be written which would be adaptable to the teaching methods of every instructor. Each one of us is forced to outline his instructional program to fit the needs at his own school. At Cooper Union we select a textbook and then use it largely as a means of home study by the student in preparation for his lectures. This plan permits the student to come to class with enough general knowledge on a particular phase of the work so that we can expand and emphasize as best suits our needs. Naturally this may mean considerable jumping around in assigning the work from the text. To encourage students to seek knowledge in books other than the prescribed text, we are careful in our lectures to include direct quotations from many sources. In doing this, we always give the origin of the quotation. Maybe some day the ideal textbook will be written, but the writer is convinced that no one author

will write it. It will probably be a compilation by a number of men, each covering a different topic, and the whole work being coördinated by an editor-in-chief. I throw this out as a suggestion to *Product Engineering* or *Machine Design* as a worth-while project for their editorial staff.

Mr. Roberts, of Howard University, brings up the question of whether we are to prepare our students for industry, or to take their natural position in life. I do not think any one will quarrel with his ideas, and the background of all our thinking should be to fit the man into his community. One aspect of such training is, however, to fit him for a life work. Every course that the student takes is given for a definite purpose, but each of these courses should have its broader aspects. I would like to quote one of the things we do at Cooper Union which we feel emphasizes this. Each year, the machine design students receive a series of lectures from the industrial design instructors of the Fine Arts School at The Cooper Union. The general tenor of these lectures is to show how the artist approaches an industrial design. This does not mean that we have gone "arty," but that we do try to convince our students that there is a definite bridge between the work of the industrial designer and the problems of the engineer. We also stress the fact that a proper solution can only be arrived at when the two work hand in hand. My staff gives a reciprocal series of lectures to the Art School students, and it is contemplated, when the exigencies of the war permit, to assign a student from each of the two schools on individual projects. By letting them work together, we will emphasize this early necessity for building a bridge between these two phases of the work. It is only by this type of work that mass production will have a mass appeal which will permit mass selling.

I would also like to emphasize some comment made by Professor Townsend, of M.I.T. I think his idea of reversing the usual procedure by giving common sense tests at the very first session of the class is a swell suggestion. The type of question he suggests is thought provoking and should arouse considerable interest on the part of the student. It is something that we at Cooper are definitely committed to try.

I have left the comment by Professor Prior of the University of Pennsylvania until the last, as I wish to amplify it somewhat. He suggested that I put more emphasis on the acceptability of graduates as engineers rather than as designers. The paper as written was tempered by the knowledge that it was to be read to the machine design group, but I cannot see why the ideas expressed in it should not apply to all engineering subjects. Machine design is not so unique that it requires a decidedly different type of presentation from other engineering subjects in the course. I do know that in our heat power and power plant courses at Cooper Union, we are doing much the same thing as we are doing in our machine design course. I will go so far as to say that if in the future we do not stress the phase of education covered by the paper, we will probably find ourselves out of line. To substantiate this I not only refer you to the Report of the Committee on Engineering Education After the War which was printed in the May 1944 issue of the JOURNAL, but in particular I would refer to the two sections headed, "Art of Engineering" and "Instructional Procedure." I would also

call attention to the two papers given on June 22; one by Professor Teare of Carnegie Institute, and the other by Professor Mavis of Pennsylvania State, on this same topic. Professor Teare forwarded to me, early in the year, the outline of the course he gives, and I recommended it to you for careful study. I do feel, however, that individual courses of the type he proposes cannot fully take the place of the inclusion of this type of material in all courses. Whenever we make a special course we tend to pigeon-hole the ideas, and the student uses them in that course, but is apt to forget that they apply in other courses too.

Mr. Luce, of Fellows Gear Shaper, in his remarks from the floor emphasized that no one method can be used and that each instructor must work out that method which will best suit his needs. He compared this to the fact that manufacturing companies among themselves have wide latitude of ideas and methods of obtaining industrial standards. In this the author is fully agreed; it was specifically stated that no attempt to set up a standard syllabus was intended. But the author does feel that the more each of us knows what the other is doing the better he will be able to make his own decision. The large number of discussions shows the interest and should provide many new ideas to try.

The author would like to suggest the revival of an idea which was tried out some time back. I remember that a number of years ago, Professor Eidman of Columbia University instituted what he called his clearing house. I do not know what happened to that idea or why it was discontinued, but it seems to me it would be a valuable aid to us if some such method of interchange of ideas and problems could be arranged.

Mechanics Division

In spite of the fact that there will be no Convention of S.P.E.E. this summer the work of the Mechanics Division will go on. Important papers which were to have been presented at conference this summer will appear in THE JOURNAL OF ENGINEERING EDUCATION. Two new members of the Executive Committee will be elected as well as a new Chairman to serve in 1946.

It seems fitting at this time to acquaint the members with our Division organization.

The Division in its present form was organized in 1930, and is governed by an Executive Committee of eight members, two of whom are elected each year for a four year term. The Chairman of the Division is a member of the Executive Committee and is elected each year by the Executive Committee. The Executive Committee has recently agreed that no chairman shall serve more than two years. There is no secretary, but it seems advisable that one should be appointed during each convention to act only during the conferences.

The membership in the Division is open not only to teachers and research men in Mechanics, but to any who are interested in Mechanics.

It is the duty of the Chairman with the help of the Executive Committee to arrange conference programs for the annual convention. In arranging conferences it is always desirable to hold at least one joint conference with some other division for the Society. Within one month following the convention the Chairman is to furnish Secretary Bishop with a running account of the conference sessions and an up-to-date list of the Executive Committe membership indicating the retiring date for each member. The Chairman also selects important papers presented during the conferences for publication in the JOURNAL.

The following is a list of the men who have served on the Executive Committee of the Mechanics Division:

1930–31, J. E. Boyd, Ohio State University; C. E. Paul, Armour Research Foundation; 1930–32, G. P. Boomsliter, University of West Virginia; S. M. Woodward, University of Iowa; A. P. Poorman, Purdue University; 1930–33, E. R. Maurer, University of Wisconsin; E. W. Rettger, Cornell University; 1930–34, N. C. Riggs, Carnegie Institute of Technology; L. Tucker, City Engineer, Urbana; 1931–35, H. D. Churchill, Case School of Applied Science; S. B. Folk, Ohio State University; 1932–36, A. E. Norton, Harvard University; F. B. Seely, University of Illinois; 1933–37, Z. R. Bliss, Brown University; W. R. Cornell, Cornell University; 1934–38, H. L. Mason, Eastman Kodak Co.; F. T. Mavis, University of Iowa; 1935–39, W. J. Cox, Yale University; H. J. Gilkey, Iowa State College; 1936–40, T. J. Dolan, University of Illinois; S. B. Folk, Ohio State University; 1937–41, W. B. Johns, Georgia Institute of Technology; C. T. Olmstead, University of Michigan; 1938–42, A. S. Adam

Colorado School of Mines; G. N. Cox, Louisiana State University; 1939–43, P. G. Laurson, Yale University; F. G. Switzer, Cornell University; J. G. McGivern, Gonzaga University; 1940–44, G. P. Boomsliter, West Virginia University; E. R. Dawley, Kansas State College; 1941–45, F. L. Everett, University of Michigan; J. O. Draffin, University of Illinois; 1942–46, S. Fairman, Purdue University; M. O. Withey, University of Wisconsin; 1943–47, C. O. Harris, Illinois Inst. Tech.; W. E. Wilson, Armour Research Foundation; 1944–48, R. V. James, University of Oklahoma; C. W. Muhlenbruch, Carnegie Institute of Technology.

E. G. Switzer resigned in 1940 and J. G. McGivern was appointed to complete his term.

The following men have served as Chairman of the Division:

1930–32, A. P. Poorman, Purdue University; 1932–33, E. R. Maurer, University of Wisconsin; 1933–36, A. E. Norton, Harvard University; 1936–39, H. J. Gilkey, Iowa State College; 1939–42, A. S. Adams, Colorado School of Mines and Cornell University; 1942–45, S. Fairman, Purdue University.

E. R. Dawley was elected Chairman in 1942, but because of special work could not serve.

SEIBERT FAIRMAN, *Chairman*